NBSIR 84-2870

Performance and Selection Criteria for Mechanical Energy Saving Retrofit Options for Single-Family Residences

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Gaithersburg, MD 20899

June 1984

Prepared for:
The Department of Energy
Office of Conservation and Renewable Energy
Washington, DC 20585

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PERFORMANCE AND SELECTION CRITERIA FOR MECHANICAL ENERGY SAVING RETROFIT OPTIONS FOR SINGLE-FAMILY RESIDENCES

Esher Kweller
Samuel Silberstein

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Abstract

Under the Weatherization Assistance Program the U. S. Department of Energy (DoE) provides funds for energy-conserving building improvements in homes of low-income persons. In proposing to modify the program to also provide funds for energy-conserving mechanical options, DoE requested that the National Bureau of Standards investigate energy-conserving mechanical options that may be suitable for inclusion in the Weatherization Assistance Program. This report estimates energy savings, and provides performance and selection criteria, standards, and installed costs for mechanical equipment options for single-family homes; all from prior studies reported in the literature. Performance and selection criteria are presented as advantages, disadvantages and limitations for each option.

Four broad categories of energy-saving mechanical options were investigated: space heating, water heating retrofit options, heat pump water heaters, and recovery of central air conditioner waste heat by desuperheaters. Gas- and oil-fueled forced-air furnaces and hydronic (hot water) space-heating equipment were treated in this report.

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1.0. Introduction

1.1. Background

Under the Weatherization Assistance Program [1] established by the Energy Conservation in Existing Buildings Act of 1976 [2], the U. S. Department of Energy provides funds to install insulation, storm windows, caulking, weatherstripping, and other improvements to the building shell, in order to conserve energy in homes of low-income, particularly elderly and handicapped, persons. The Department of Energy is now proposing to modify the program to make it more "balanced" [3], that is to also provide funds for energy-conserving mechanical options.

1.2. Objectives

The Department of Energy requested that the National Bureau of Standards identify energy-conserving mechanical options that may be suitable for inclusion in the Weatherization Assistance Program, estimate their energy savings, and provide performance and selection criteria. This is done in this report for single-family homes; results for multiple-family homes are reported separately.

1.3. Scope

The energy-savings estimates of mecahnical options, and performance and selection criteria were derived from prior studies reported in the literature. Performance and selection criteria are presented as advantages, disadvantages and limitations for each option. Since selection criteria depend upon local codes, circumstances such as equipment age, and local fuel and electricity costs, decisions as to which options to be used should be made at the local level.

Standards concerning equipment and its installation are listed for each option, as are installed costs. Some equipment costs are also given for new commercially available products that may not have been previously reported. Payback times are outside the scope of this report, but are included if they are available in the literature.

Section 3 recommends the order in which these options should be considered. A more detailed description of each products' energy savings alone, and in some cases in combination with other options is presented in Sections 4 to 7 together with references.

2.0. Descriptions of and selection criteria for energy-saving mechanical options

Four broad categories of energy-saving mechanical options were investigated: space heating, water heating retrofit options, heat pump water heaters, and recovery of central air conditioner waste heat by

desuperheaters. Gas- and oil-fueled forced-air furnaces and hydronic (hot water) space-heating equipment were treated in this report. Following in this section are brief descriptions of these options and estimated energy savings potential where such data are available.

2.1. Space-heating systems

Before investing in retrofit equipment for a furnace or boiler, the heat exchanger should be examined to ensure that it is not defective. Guidelines for inspecting the heat exchanger are in section 8.2.2.

2.1.1. Derating with control of excess combustion air

Derating reduces the rate of fuel and air admitted to a burner. Derating is done for the purpose of providing a better matching of the maximum heat output of the furnace or boiler to the design heating requirement. Approval of this option is dependent upon local codes. Manufacturers of gas furnaces and boilers do not encourage derating, and it may nullify their warranty.

Advantages

Energy savings averaging 9% have been reported for gas-fueled heating systems. For oil-fueled heating systems, energy savings are 8.7% in forced air systems, and 2.6% in hot water systems.

Off-period losses are decreased by the reduced number of burner cycles.

On-period combustion efficiency may increase.

Little or no material cost is required for derating gas-fueled equipment.

Disadvantages/limitations

Derating may void warranty of gas-fueled furnace.

Derating may violate local building codes.

Derating could lead to severe safety problems unless done by qualified personnel, especially for gas furnaces.

Derating may reduce life of heat exchanger (especially counterflow type) in gas-fueled furnaces.

Derating should be limited to not more than 40% of maximum rated input to avoid condensation problems.

Replacement of the combustion chamber liner may be required in order to improve the efficiency of oil-fueled equipment.

Derating is not applicable to boilers equipped with domestic water heating coil (unless a separate hot water storage tank is used).

Field tests showed no savings with steam-boiler systems.

2.1.2. Replacement oil burners

Flame retention head burners use a fuel-air mixture that requires less excess combustion air than conventional burners.

Advantages

For oil-fueled boilers, energy savings over 20% have been reported. For oil-fueled furnaces, energy savings of 8% have been reported.

Replacement burners save the cost of replacing entire furnaces, particularly when several years of life remain.

Disadvantages/limitations

Incompatibility of the more intense combustion or smaller flame size may require the combustion chamber to be modified.

2.1.3. High efficiency gas conversion burners

Many old coal-fired heating systems have been converted to heat with gas by replacement with gas conversion burners, most likely atmospheric type. Since 1979, powered gas conversion burners have been marketed. Converting from old atmospheric to powered gas conversion burners saves energy because the newer burner operates with less excess combustion air. Recently, oil-fueled furnaces and boilers have been converted to gas (where the cost of fuel oil was disproportionately higher than gas). These burners are most likely to be the powered type.

Advantages

Newer powered gas conversion burners offer higher combustion efficiency and reduced off-period loss as a replacement for older atmospheric-type gas conversion burners. Powered burners offer flexibility of derating to a more efficient firing rate. Combustion efficiency improvement of 15% has been reported at steady-state operation. The installed part-load efficiency improvement would be even better since off-period loss is reduced with a powered burner.

Disadvantages/limitations

May not be advisable for older equipment with deteriorated heat exchanger having limited remaining life.

2.1.4. Vent dampers

A vent damper is an electromechanically or thermally operated valve installed between the draft diverter and the vent connector with a movable plate that closes to prevent heat loss during heating system off-cycles.

Vent dampers for water heaters are similar to those for space-heating systems.

Advantages

Reduced off period losses for all types of dampers installed indoors.

For gas-fueled heating systems, energy savings averaging 5% have been reported.

For oil-fueled heating systems, energy savings averaging 8-9% have been reported.

Thermal-type vent dampers offer the possibility of low-cost installation.

Disadvantages/limitations

Full potential savings can only be achieved if furnace or boiler is installed in an area communicating with the heated area of the home (that is, not as useful if furnace is in attic or crawl space).

Installation can lead to severe safety problems unless done by qualified personnel.

A water heater vented through a common stack with the furnace should also be equipped with a stack damper to maximize savings.

2.1.5. Reduced excess dilution air

In many homes retrofitted to reduce heat loss or with thermostat setback, the furnace may either be replaced with a smaller unit or the input rate reduced to better match the new heating requirements (as described under Derating). Consequently, the venting system will be oversized. It may have been oversized with the original furnace as well. This results in excessive stack draft. The consequent flow rate of heated room air out the stack is considerably greater than needed for flue gas dilution. This is particularly true for older homes with tall masonry chimneys which are generally larger in cross-sectional area than factory-built chimneys. Reduced excess dilution air at the draft control device can be achieved in gas-fueled equipment by reducing the cross-sectional area of the vent connector. Excess stack draft can also be reduced by using a small section of pipe in the vent connector with reduced cross-sectional area, without replacing the entire vent connector pipe.

Advantages

Low cost of materials for resizing vent connector pipe.

Reduced on- and off-period infiltration losses.

Energy savings of 3.7% have been reported for gas-fueled heating systems.

Disadvantages/limitations

Installation can lead to severe safety problems unless done by qualified personnel.

2.1.6. Flue gas heat reclaimers

Flue gas heat reclaimers are devices that capture heat that would normally be exhausted out the flue.

Advantages

Energy savings of 6.6% have been reported for gas-fueled heating systems and 10% for oil-fueled furnaces. New designs using water spray to recover stack energy claim even greater savings.

Flue-gas heat reclaimers offer an alternative solution to saving energy when stack loss cannot be reduced by increasing existing burner efficiency by tuneup or reduced input rate.

Disadvantages/limitations

Most effective type of heat extractor is relatively expensive, approximately $600 plus installation cost. Therefore use of this option should be based on expected remaining useful life of the furnace heat exchanger.

Installation should be done only by qualified personnel properly trained. Space limitations in the furnace room could restrict some installations.

2.1.7. Thermostat controls

2.1.7.1. Automatic or manual boiler water temperature reset control

Automatic boiler temperature reset control allows for using a boiler water temperature which more closely matches the amount of heat needed to maintain comfortable room temperature for a given outdoor air temperature. This controller automatically raises the circulating boiler water temperature set point as outdoor temperature drops, and reduces the water temperature setting in milder weather. Energy is saved due to reduced cycling of the burner, and less heat is lost out the stack during the off period. (This is particularly important in the absence of a stack damper.) This is particularly applicable for systems which maintain boiler water temperature to independently heat several zones with the same hot water boiler (usually two or more separate zones or apartments).

Advantages

Reduces off-period losses. Energy savings of 10% have been reported.

Manual reset is a simple adjustment.

In homes with too few radiators, the boiler output is excessive and the boiler cycles on the high limit control, wasting energy. If it is possible, the number of radiators should be increased. If this is not possible, reducing the boiler water temperature would reduce short cycling.

Disadvantages/limitations

Most effective type (automatic reset control) is expensive.

Not applicable when domestic water heating coil is used.

Reducing water temperature too low could cause excessive condensation on heat up on the flue gas side and reduce heat exchanger life.

2.1.7.2. Setback room temperature thermostats

Setback thermostats are thermostats that allow different temperatures to be set for different times of the day or night. Manual reset can achieve the same results but is less likely to be practiced diligently.

Advantages

For homes with oil-fueled boilers, energy savings of 9% have been reported (8% for gas furnaces with 3°C (5°F) night setback).

Disadvantages/limitations

Setback is limited by the possibility of pipe freezing. This can be corrected by using electric heating tape and piping insulation for remote areas or where water pipes pass through less heated areas of the house. For the very young and old, setback may not be safe or comfortable.

2.1.7.3. Fan delay blower temperature control

Fan delay blower temperature control adjustment both after burner turn-on and shut-down can be optimized without compromising comfort to recover heat that would otherwise be lost out the stack.

Advantages

Setting the fan delay blower temperature control is a simple adjustment requiring no additional materials.

Gas energy savings of 6800 MJ/year (64 therms/year) has been reported. Electricity use has been reported to typically increase by 610 MJ/year (170 kWh/year) since the blower motor must operate longer. However, with utility rates of $0.0066/MJ ($0.70/therm) for gas and $0.017/MJ ($0.06/kWh) for electricity, savings amount to $35/year without need for any equipment and minimal labor cost. (The adjustment can be accomplished on some units with a screwdriver, and on most units by moving a manual control dial.)

Disadvantages/limitations

Not as effective where electricity costs are high because requires additional electricity to operate fan motor.

2.1.8. Replacement furnaces and boilers

Furnace or boiler replacement may be justified if the present furnace is oversized, operates at low efficiency, and cannot be derated. If the heat exchanger is defective, the entire furnace or boiler must be replaced.

Section 4.8 includes methods for estimating oversize, and for estimating expected energy savings of furnaces and boilers with a known annual efficiency.

Advantages

Recently, a wide variety of new equipment, especially gas furnaces and boilers, has become available that achieves much higher efficiencies, and hence energy savings, than even well-tuned older equipment. Additional savings may result because replacement equipment also allows proper sizing, which may not always be possible for older equipment.

Disadvantages

The cost of an installed new unit, especially a boiler, may exceed the guidelines of the weatherization program in areas with high labor costs (see section 4.8.1 for expected costs).

2.1.9. Electronic pilot ignition devices

Intermittent ignition devices ignite gas to begin the combustion on-cycle, eliminating the need for a constantly burning pilot light.

Advantages

Energy savings of 4.4% have been reported. Greater savings apply if central air condtioning is used at the same time as a constantly burning pilot is operating.

Disadvantages/limitations

There are no energy savings in replacing the pilot if the pilot is turned off for the non-heating season.

Installation can lead to severe safety problems unless done by qualified personnel.

2.1.10. Insulating exposed duct work

Insulation of exposed duct work saves energy both during the heating and cooling seasons (with central air conditioning). Exposed ductwork in unheated basements, crawlspaces, and attics are important. Before sheetmetal is insulated, any leaks at the seams of the duct work should be covered with duct tape.

Advantages

Insulation of exposed ducts in unheated areas can reduce heat loss. Energy savings of up to 2.6 $W/m^2 \cdot {}^oC$ (1.5 $Btu/h \cdot ft^2 \cdot {}^oF$), or 40% of the heat output of a furnace, have been reported for the not uncommon condition of leaking ducts.

Cost of insulation and labor is small compared to the potential energy savings.

Disadvantages/limitations

It may not be possible to insulate inaccessible duct work.

2.1.11. Zone control

Radiator valves for hydronic systems -- either manual or thermostat-controlled -- permit each radiator to be individually controlled. Alternatively, radiator and warm air register covers can be used in unoccupied rooms.

Advantages

Energy savings up to 40% have been reported.

Added radiator controls are not expensive, and result in not heating little used areas of the house.

Disadvantages/limitations

Installing zone control is expensive for forced-air systems.

2.2. Water heating options

2.2.1. Reduced excess dilution air

Whenever a water heater is replaced by one with a smaller burner input capacity, or when venting system is oversized, space-heating energy can be saved by reducing excess dilution air (see 2.1.5 for more details).

2.2.2. Reduced thermostat settings

Hot water storage temperature can be reduced by reducing the thermostat setting.

Advantages

Energy savings up to 12% have been reported.

Unskilled personnel can adjust thermostats on all types of water heaters.

Disadvantages/limitations

Themostat settings cannot be reduced where there are automatic dishwashers that do not preheat water, since they require an inlet water temperature of 60°C (140°F).

2.2.3. Add-on insulation of tank

An insulated blanket cover over the water-heater jacket may reduce water heater jacket losses.

Advantages

Savings up to about 9% have been reported.

Insulated blanket covers cost little for all types of water heaters.

Disadvantages/limitations

There are no disadvantages in using insulated blanket covers on electric water heaters. Because the stack loss of gas-fueled water heaters amounts to 50% of the standby loss, jacket loss savings are less than for electric water heaters.

2.2.4. Insulation of distribution pipe

Uninsulated hot water pipes lose heat both when hot water is being drawn or during standby.

Advantages

Three percent of the energy used to heat water can be saved by insulating the first 7.6 m (25 ft) of distribution pipe.

This option is particularly advantageous where hot water pipe passes through unheated areas or where hot water continuously circulates in larger buildings with long piping runs.

Disadvantages/limitations

Some pipes may not be accessible for insulation.

2.2.5. Heat traps

Heat traps are curved sections of pipe that brake the natural tendency of heat to rise out of a water heater.

Advantages

Heat traps can save energy at a rate of approximately 17 W per water heater. Savings would be lower if riser pipes are insulated.

Heat traps involve low cost for materials.

Disadvantages/limitations

Heat traps require replumbing inlet and outlet lines. Therefore installation is only justified if done at the same time as water heater replacement. Insulating the pipe could probably save as much energy as heat traps.

2.2.6. Vent dampers

Vent dampers for water heaters are similar to those for space-heating systems. A double damper which closes at both the flue and the draft hood outlet has been approved for residential gas water heaters (under the classification "mechanical dampers") but is not being marketed at present.

Advantages

If both the water heater and furnace are located in a heated area, gas savings can be as high as 4700 MJ/year (45 therms/year) for both.

A thermal stack damper is easy to install on a gas-fueled water heater since it does not require an electric hookup.

Disadvantages/limitations

Vent dampers save little energy in regions with a mild heating season, because energy recovered at the water heater does not greatly reduce space heating load.

Only thermal vent dampers can be installed on gas-fueled water heaters because water heaters don't have the necessary electrical wiring for electrical dampers.

Installation can lead to severe safety problems unless done by qualified personnel.

2.3. Heat pump water heaters

Heat pump water heaters are normally considered as replacements for electic water heaters. Heat pump water heaters transfer heat from the air in the room surrounding the device into the water tank, using a vapor-compression cycle similar to that of a window air conditioner.

Advantages

Heat pump water heaters typically save 47% of the electricity used to heat water, or 10,500 MJ/year (2917 kWh/year).

Heat pump water heaters help reduce cooling load in areas with long cooling seasons.

Heat pump water heaters located in basements dehumidify basement air.

Disadvantages/limitations

The high cost ($800-1200) would limit the applicability of heat pump water heaters to areas where high electric rates justify the initial cost.

Heat pump water heaters should be installed in well-ventilated areas in order to avoid lowering the temperature of the air surrounding the unit.

2.4. Heat recovery from air conditioners

A desuperheater heat recovery unit transfers heat from superheated refrigerant in an air conditioner to a water tank via a heat exchanger.

Advantages

Energy savings are estimated to be 2900-4300 MJ/year (800-1200 kWh/year). This amounts to $40-60/year assuming electricity costs of $0.014/MJ ($0.05/kWh).

Desuperheaters save energy in homes using central air conditioning systems for long periods. They may also improve central air conditioner operating efficiency.

In the southern half of the United States, it may be possible to disconnect the electric power to the water heater at the start of the cooling season, heating water during the summer completely with waste heat from the central air conditioner.

Disadvantages/limitations

Large energy savings at the water heater are predicated on extensive use of the central air conditioner. The ability to reduce central air conditioning use by substituting whole house fans for cooling would probably save more energy than desuperheaters would recapture.

2.5. Maintenance

Maintenance of furnaces and boilers, water heaters and central air conditioning systems is described separately below, followed by common advantages and disadvantages/limitations.

2.5.1. Gas- and oil-fueled furnaces and boilers

Replacement of air filters and removal of dust from the fan compartment are recommended to maintain the air flow rate, and therefore the heat transfer rate, at their design levels. Others checks on operation, as detailed in the National Fuel Gas Code for gas furnaces, are important for safe operation. Cleaning of combustion chambers and heat exchangers is required to maintain proper operating efficiency of oil-fueled equipment. Soot buildup due to poor combustion is a cause of efficiency degradation in oil-fueled equipment.

2.5.2. Water heaters

Silt and scale should be removed from storage tanks of all water heaters.

The comments about oil-fueled furnaces and boilers apply to oil-fueled water heaters as well.

2.5.3. Central air conditioning systems

Replacement of air filters, cleaning indoor and outdoor heat exchanger coils, and proper refrigerant charge are recommended for central air conditioning systems.

Advantages (of maintenance of furnaces and boilers, water heaters and central air conditioning systems)

Maintenance may save energy, improve comfort, reduce incidents of failure, and identify unsafe operating conditions.

Disadvantages/limitations

There are no disadvantages or limitations to proper maintenance.

3.0. Recommended Approach to Retrofit for Mechanical Equipment Options

In section 2 the various mechanical options presented were not presented in sequence in which they should be done. However, when approaching heating equipment for retrofit there is a logical order of proceeding. Since there are many possible variations for installations across the country there will also be variation to the approach presented here. A change of fuel type with replacement of equipment has not been considered here. It is assumed that type of fuel in use would continue as presently in use.

An approach for all types of space heating systems is presented as a flow chart in figure 1. and for water heaters in figure 2. Figure 1. begins with the two most common retrofit options which are applicable to all types of heating systems - insulation of the heat distribution ductwork or piping, and installation of a night setback thermostat. After these are completed, an examination of the furnace or boiler heat exchanger is recommended before proceeding with any further retrofitting. If the heat exchanger is defective as determined by the presence of combustion products through the heat exchanger in a hot air system or of water leaking in a boiler, then retrofit of that equipment should not be attempted and the unit should be replaced. If the heat exchanger is in good condition, the approach to retrofitting should be as shown in figure 1. for the heating systems. In that figure the words "consider installation" are used because the type of installation and the heating systems physical location may control the applicability of specific options. For example, it would not be prudent to install a vent damper on a furnace which is either installed outdoors or does not communicate in any way with a heated area of the home, (i.e. an unheated garage, a crawl space or an attic). It is also not prudent to install electric ignition on a gas furnace in a unit where the occupant is capable of and diligently turns off the pilot during the non-heating season and relights the pilot without assistance.

For vented room heaters, which may be the type of heating system used in milder climates, the options that apply are simply to check combustion, and adjust the combustion air if necessary to increase efficiency to 70%, and to consider installation of a vent damper. On most room heaters, a vent damper would be justified since it is installed in the room being heated. It would not be appropriate for a floor furnace installed in a crawl space.

One type of water heating system which has not been included in figure 2 is the combination boiler/water heater; also referred to as the tankless coil type system. It has been shown that considerable space heating energy savings can be achieved by using an add-on tank to that system in order to allow for derating when an oil burner is used. In addition, considerable water heating/energy savings can be achieved by substituting a tank type of water heater for use during the non-heating season, and shutting down the boiler during that period. See section 5.7 for further details.
The only options being considered for the central air conditioning/heat pump systems is maintenance, which can be a very important option to saving energy for those systems. See section 8.1.

Each pertinent sub-section of sections 4 and 5 should be referred to as indicated in figures 1 and 2 before a decision is made on which type of retrofit is to be used.

4.0. Space heating system energy saving retrofit options

Normal operation of heating systems wastes energy in several ways. For example, Brookhaven National Laboratory [4] found that operating stack losses accounted for 15-35% of the available heat in the oil, operating jacket losses 0-10% and off-cycle losses 5-15%. Brookhaven National Laboratory found that seasonal (annual) overall efficiency of oil-fueled boilers ranged from 55% to 75%. Efficiencies above 80% are now attainable by retrofitting both gas- and oil-fueled heating systems.

Energy can be saved in residential heating systems by raising burner efficiency, minimizing heat lost up the chimney (operating stack loss), heat lost through the boiler casing or furnace to its surroundings during burner operation (operating jacket loss), and heat lost when the burner is not operating (off-cycle losses).

Improved steady-state efficiency is far from the whole story, however. Much wasted heat is lost during off cycles. Therefore, overall heating-system efficiency at part load, more than steady-state efficiency, determines seasonal efficiency [5]. Figure 3 shows the effect of burner on-time on seasonal efficiency of boilers having conventional and flame retention head oil burners, and standard and improved boiler heat exchanger surfaces. Table 1 and figure 4 show the factors that affect seasonal efficiency, and design routes to raise seasonal efficiency.

Estimates of energy saved by the mechanical options described in this report are derived from what are believed to be the best available sources. Field test results are considered preferable to laboratory investigations, which are in turn considered preferable to computer simulations. It should be borne in mind that energy savings are mean values of population distributions whose range can often be twofold. Details of these energy savings distributions can be seen in some of the references cited.

Before beginning any major retrofit to a furnace or boiler, an examination of the heat exchanger is recomended in order to confirm that it is not defective. Section 8.2.2 includes guidelines for checking the heat exchanger.

4.1. Derating with control of excess air

Derating is done for the purpose of providing a better matching of maximum furnace or boiler heat output to the design heating requirement. Oversized systems cycle more frequently than properly sized systems because they provide excess heat. Each time the system is turned on, heat must be provided to bring it up to operating temperature. When it is turned off, residual heat remaining in the heat exchanger is lost out the open stack (if a stack damper is not used). Derating reduces the rate of fuel and air admitted to a burner, reducing cycling frequency. It is not an acceptable option if it violates local building codes.

There are several reasons why houses may have oversized heating systems. They might have been deliberately planned as a safety factor; changes in the house, for example conservation measures, might have lowered the heating requirement since the heating system was installed; heating load might have been improperly calculated [6].

Derating may increase comfort because it reduces the number of hot-cold cycles corresponding to heating system on-off cycles. Derating does, however, increase the probability of heat exchanger corrosion. Because fans operate when the heating system is on, and derated systems are on longer than unmodified systems, electrical use is slightly increased [6].

Derating a heating system must be weighed against replacing present equipment with properly sized equipment. If the heating system is in poor condition, replacement may be a better option. (Criteria and procedures for installing new oil burners are described by the National Bureau of Standards and the Department of Energy [7].) Optimum oversize is between 50 and 60% because this extent of oversize is required for recovery from night setback [8].

Oak Ridge National Laboratory [9] estimates that gas-fueled furnaces oversized by a factor of two require 8-10% more gas than properly sized furnaces.

The American Gas Association [10] describes a detailed method for calculating fuel input requirements for design conditions. The procedure requires knowledge of gas consumption based on gas bills for four months of the previous heating system. A simpler, less detailed procedure is presented by the "Consumer reports money saving guide to energy in the home" [11] for oil furnace derating; the authors do not recommend derating of gas furnaces. However, the procedure is considered here to be applicable to any type of heating system and fuel. One measures the furnace burner on time during at least one hour and derives a size factor by a calculation that accounts for the temperature differences between that time and the design day. From the design factor, one determines whether the furnace input rate is large enough to derate. A "Procedural guide to derating gas appliances" is included in the "AGA manual for field service

and adjustment of gas space heating equipment" [6].

4.1.1. Gas-fueled heating systems

Manufacturers of gas furnaces and boilers do not encourage derating, and it may void their warranties.

Gas heating appliances may be derated by reducing the size of main burner orifices, reducing gas pressure, or both. The American Gas Association [6] states that reducing orifice size is generally safer than reducing pressure, and that the frequency of ignition problems increases when the design pressure of the burner is altered.

Derating by itself would increase the amount of excess air and reduce flue gas temperature because less gas would be burned than before derating. Consequently, little or no energy would be saved. Internal flue restriction by baffling the heat exchanger is required to restore carbon dioxide concentration — or equivalently, control excess combustion air — to the same levels as before derating. Figure 5 shows the entry points of combustion and dilution air in a furnace and water heater.

The Gas Industry [12] performed a conservation study, the Space Heating Efficiency Improvement Program (SHEIP), on 2650 North American houses over three years. The results are shown in table 2. It can be seen in table 2 that derating gas without derating combustion air reduces gas use by only 1.5%. In combination with flue restriction, that is, control of excess combustion air, derating fuel reduces gas consumption by 6.2%.

A detailed analysis of 65 of the SHEIP houses [13] was used to derive approximate regression relationships between expected fuel savings due to derating fuel and change in furnace steady-state efficiency, fuel input derate and vent area restriction. The relationships are:

for furnaces alone:

$$\Delta C = 0.42\ \Delta E + 0.19 \Delta D + 0.03 \Delta V$$

for boilers alone:

$$\Delta C = 0.68\ \Delta E + 0.11 \Delta D + 0.05 \Delta V$$

for furnaces and boilers:

$$\Delta C = 0.48\ \Delta E + 0.16 \Delta D + 0.03 \Delta V$$

where

ΔC = percentage change in gas consumption

ΔD = percentage change in fuel input derate

ΔV = percentage change in furnace vent open area restriction

ΔE = percentage change in steady-state efficiency

As can be seen, change in furnace steady-state efficiency is the most important factor in this study. However, derating and vent restriction are required for improved efficiency.

One potential negative aspect of derating gas furnaces has been the potential for accelerated heat exchanger corrosion due to condensate (which is acidic) deposits due to lower flue gas temperatures (possibly below the dew point on cold spots). Rochester Gas and Electric Company derated more than 60 residential gas furnaces in 1977. The conclusions of that study (14) were that, with regard to corrosion and furnace derating:

- Furnace design is important.

- Indoor contaminants may be important.

- Approximately 50% of the derated furnaces were in good condition after four years.

- Some furnaces corrode too much whether you derate them or not.

In that study, it was found that furnaces were 50 - 150% oversize in Rochester. The derate procedure used included reducing the speed of the blower so that the cooling effects of the combustion chamber was reduced. This would tend to make any heat exchanger cold spots warmer.

This Rochester Gas and Electric Company (RG&E) program of derating was offered to the public in 1977 on a limited basis via trained local heating contractors. Homeowners paid $142 to have their central heating systems derated. This program resulted in an average 15% reduction in gas fuel usage for equivalent total number of degree days. The savings ranged from 2% to 37%. Details of the RG&E study includes a selection procedure used to identify potential sites for retrofit and discussion of the training of contractors. See Ref. (15).

4.1.2. Oil-fueled heating systems

Honeywell [16, 17] analyzed reductions in oil use in 26 New England homes in which burners were derated by having their nozzle sizes reduced. Firing rates were reduced an average of 27%. Average seasonal oil savings were 8.7% in forced air systems, 2.6% in hot water systems, and energy use increased in steam systems. (Steam systems consume an insignificant quantity of energy in the U.S. compared to other residential heating systems.)

Walden Research [18] reduced the firing rates of 18 oil-fueled heating systems by an average of 36% and obtained average seasonal fuel savings of 14%. Steady-state efficiency was increased from 69% to 76%.

Walden Research [18] installed reserve domestic hot water storage tanks ("aquaboosters"; see figure 6) in eight hot-water systems with tankless coils for domestic water heating. Without this retrofit, firing rate could not be lowered below 4.75 l/h (1.25 gal/h). Below that rate, enough hot water could not be delivered. This retrofit made it possible to reduce firing rate an average of 34%. Average seasonal fuel savings were 12% and average steady-state efficiency increased from 71% to 76%. The effect on

the hot water energy requirement of this retrofit for the summer months was not evaluated by this study.

Brookhaven National Laboratory [4] found that overall efficiency of oil-fueled furnaces increased from 72% when the burner was on 10% of the time, to 82% when the burner operated continuously.

A procedure for optimizing nozzle size is described in "A service managers guide to saving energy in residential oil burners" [19] and in "A guide to efficient oil heating in homes" [20].

4.2. Replacement oil burners

Flame retention head burners (figure 7) provide an atomized fuel-air mixture that requires less excess combustion air than conventional burners. Because flames are hotter, heat transfer and combustion performance are improved [21]. Smoke and pollution are claimed to be reduced almost to zero [22]. Air flow rate, and therefore heat losses, during off cycles are reduced because the burner offers more flow resistance during the off cycle.

Routinely installed retention head burners save 11% of fuel oil annually, while optimally installed burners save 18%. Optimal fine tuning included sealing off air leakage, cleaning the heat exchanger and combustion chamber, reinsulating the boiler and adjusting the draft. Routine tuning consisted of annual maintenance, including cleaning. In both cases, combustion chambers were repaired or replaced as necessary. Routinely installed burners cost $325-425 in 1981. Optimally installed units cost $390-425. Replacement combustion chambers cost an additional $60-100.

Brookhaven National Laboratory [4] tested seven different kinds of oil-fueled flame retention head burners. These burners operated at seasonal efficiencies of 70-75%, compared to 56% for a conventional burner. Stack losses were reduced from 21% for the conventional burner to 12-18%. Jacket and off-cycle losses were also reduced. Annual oil use was reduced 17-23%, from 5320 L (1405 gal) to 4110-4390 L (1087-1161 gal).

Oil-fueled furnaces were also tested. Combustion chambers were routinely relined and the heat exchangers were cleaned prior to burner installation. Firing rates were reduced and the equipment was properly tuned. The furnace recirculating fan control was adjusted to start fan operation as soon as possible after the burner started, and to maintain fan operation as long as possible after burner shut-down. The burner refit test produced typical annual savings of 8%. The burner cost $460, including the new combustion chamber liner. Retention head burners increased steady-state efficiency from an average of 68% to an average of 78% in 22 oil-fueled furnaces. In 17 houses using retention head burners in combination with vent dampers, the steady-state efficiency was 77%.

Installation of seven new flame retention head burners, with firing rates reduced an average of 43%, produced average seasonal fuel savings of 30%. Excess air was reduced by 52%, and steady-state efficiency increased 29% [18].

The Department of Energy [23] retrofit 200 heating systems of low income

families with flame retention burners. The purposes of the study were to test whether the high savings found by Brookhaven National Laboratory could be duplicated in typical low income homes, and to develop an administratively simple program. Average fuel use reduction of just over 20%, compared to conventional burners, was achieved. Administrative simplicity was achieved by paying contractors a fee of $500 to raise steady-state burner efficiency to 80%. The program was since expanded to over 11,000 homes in different regions of the United States.

Oak Ridge National Laboratory [24] reported that installation of a retention head burner in a home eligible for low-income weatherization assistance cost approximately $400 and reduced fuel requirements by 18% on average. Oak Ridge further estimated that because furnaces eligible for weatherization are older and presumably less efficient than typical furnaces, and because the firing rate of the burner can be reduced simultaneously, burner replacements done under the weatherization program are likely to produce energy savings of 20% or more.

Guidelines for, and a discussion of, replacement criteria, selection and installation of replacement burners, and post-installation prodedures can be found in reference [7]. Specific installation instructions for five manufacturers' flame retention head burners are given in reference [20].

The NBS Special Publication No. 606 (7) includes the following criteria:

> Replace the burner only if the estimated savings resulting from installation of a more efficient burner will pay for the cost of the replacement burner. If the savings calculated, multiplied by the homeowner's desired payback period in years exceed the total cost of burner replacement (labor plus parts), the burner should be replaced.

Table 7 shows the annual dollar savings per $100 of annual fuel costs that can be achieved by increasing furnace efficiency.

Another set of criteria for replacing oil burners is given in (47), where the following reasons are given for replacing an oil fired burner:

- Low Combustion Efficiency
  Replace if after adjustment and tune up, steady state effiency could not be raised above 60%.

- High Smoke Levels
  Replace if the steady state efficiency after tune-up is between 60% - 70% with the smoke number in excess of 3 on the Bachrach scale.

- Inability to Reduce Firing Rate
  If the reduced firing rate adjustment procedure results in shifting to larger and larger nozzle sizes until the original size is again reached the burner should probably be replaced.

4.3. High efficiency gas conversion burners

Many coal burners were converted to gas- or oil-fueled burners twenty-five or more years ago. The gas burners used then were atmospheric with continuous pilot burners. High efficiency power burners are available today which can improve both steady-state and seasonal efficiency. Power burners can also be equipped with spark ignition systems rather than continuous pilot burners. The tight construction of power burners reduces the air flow rate through the burner section, reducing off-period stack losses. Power burners can be derated to the proper heat input rate for a given heating load, whereas it may be impossible to effectively derate the old atmospheric gas burner. Consumers Union [11] tested and compared the efficiency of a power conversion and atmospheric burners; combustion (steady-state) efficiencies were 79-83% for power burners compared with 74% for atmospheric burners.

4.4. Vent dampers

A vent damper is a valve installed between the draft diverter and the vent connector of a gas- or oil-fueled combustion applicance, with a movable plate that closes to prevent heat loss during burner-off cycles.

Flue gases must be vented outdoors to maintain occupant health, safety and comfort. Flue gases are vented through a chimney by the tendency of hot gases to rise. This means that a certain amount of heat retained in the metal of the heat exchanger is lost out the open vent when the burner cycles off. Because a 70% oversized burner in a heating appliance typically cycles on and off about 17,500 times per year, this can be a significant loss, and more so with units that are oversized to a greater extent. The amount of lost heat can be minimized if the stack is equipped with a damper that constricts the flow of flue gases when the main burners are off [6].

Because a vent damper is located above the draft diverter, heat can spill out of the draft diverter into the adjoining space rather than exit through the chimney. In addition, a vent damper lessens the amount of warm house air that spills out the chimney. There are three types of vent dampers: thermal, electrical and mechanical. Thermal dampers require no electricity to open and close but depend on the expansion of heated metals (figure 8). Electric dampers (figure 9) use either electric motors or solenoids to open and close dampers. Mechanical dampers usually open when gas pressure is high enough and close when pressure drops; they are not commercially available at present. Thermal dampers are the only practical dampers to use in water heaters because they are not wired for electrical dampers.

Vent dampers, except for thermal dampers [25] cannot save any energy during the on cycle. Even during the off cycle, they do not all close completely [6]. Energy savings depend on thermal communication between the area surrounding the heat exchanger and the rest of the house. If there is little communication, heat spilling out the draft hood or draft diverter into the surrounding area serves no useful purpose.

If common vents serve two or more appliances such as the water heater and furnace or boiler, a separate vent damper must be installed in each vent connector in order to maximize energy savings (figure 8). If dampers are

not installed for each appliance, there will be increased draft in those connectors without vent dampers (figure 8). This is illustrated by a laboratory study performed by the National Bureau of Standards [26]. Compared to not using any vent dampers at all, energy savings at the water heater of 28.9 MJ/day (27,400 Btu/day) were measured when both a furnace and water heater were equipped with vent dampers, while an extra 39.8 MJ/day (37,700 Btu/day) were lost by the water heater when only the furnace was so equipped. Some electric dampers may require the installation of an additional safety shut-off gas valve. Manufacturers' installation instructions should specify if this is necessary.

4.4.1. Gas-fueled heating systems

With total communication between the area containing a gas heating system and the remainder of the house, gas savings up to 15% are possible. Homes with heaters located in unheated basements are expected to conserve little gas even if there is communication between the basement and the rest of the house [13]. Overall savings in 146 houses with vent dampers were 5.1% (table 2) [12].

4.4.2. Oil-fueled heating systems

Katzman and Monat [25] installed motorized flue dampers in 21 houses heated by oil and obtained seasonal fuel savings of 6.5%. They estimated savings by a National Bureau of Standards calculation procedure [27] to be 8.2% for the average U. S. climate assuming that all units were 70% oversized [25]. Two different types of dampers were used, as were two types of burners: conventional and flame retention head. Fuel savings differed by 1% or less among these. Savings were highest for steam boilers, lower for hot water boilers, and least for warm air furnaces.

Hoppe and Graves [21] measured savings of 9% in oil-fueled boilers using electromechanical vent dampers. The installed cost in 1981 was $295. Vent dampers save no additional energy when installed on optimized flame retention head burners.

4.5. Reduced excess dilution air

4.5.1. Resized vent connector

Reduced excess dilution air through the draft control device can be achieved in gas-fueled equipment by reducing the cross-sectional area of the vent connector (figure 5). In many homes retrofitted to reduce heat loss or with thermostat setback, the furnace may either be replaced with a smaller unit or the input rate reduced to better match the new heating requirements (as described under <u>Derating</u>). Consequently, the venting system will be oversized. It may have been oversized with the original furnace as well. This results in excessive stack draft. The consequent flow rate of heated room air out the stack is considerably greater than needed for flue gas dilution. This is particularly true for older homes with masonry chimneys which are generally larger in cross-sectional area than factory-built chimneys. This condition can also be corrected by using a small section of pipe in the vent connector with reduced cross-sectional area, without replacing the entire vent connector pipe. It is important that whatever method is used, the vent pipe be visible for internal

inspection. Energy savings of 3.7% have been reported for vent resizing in gas-fueled heating systems [12].

4.5.2. Forced exhaust

An alternative to rebuilding a masonry chimney or replacing a factory built chimney when a chimney needs extensive repairs is direct side-wall venting by a mechanical exhaust fan or power vent through the nearest outside wall, as is done with clothes dryers. Side-wall venting is commercially available and is most applicable to products that have electrical hook up. Power venting can be adapted to gas-fueled water heaters even though they do not have electrical hook up, by installing a commercially available isolated electrical junction box [28]. The advantage of power venting over natural draft is reduced off-period loss. The vent is practically closed during burner off periods.

4.6. Flue gas heat reclaimers

Flue gas heat reclaimers are devices that capture heat that would normally be exhausted out the flue (figures 10 and 11). An additional heat exchanger can be attached to the flue to reclaim some of the heat exiting from the furnace or boiler heat exchanger. This heat can be used directly for space heating, or for preheating water or return air [25]. Flue gas heat reclaimers used together with derating may cause condensation. Whether condensation occurs or not is unimportant for water-spray type heat exchangers (see below).

Katzman and Monat [25] obtained oil savings of 6.6% with four flue-gas heat reclaimer devices in houses using oil-fueled burners. Three of the devices were commercial "heat pipes", and one a homemade air-to-air heat exchanger. (Energy savings were not directly measured but were determined by a simulation model.) The homemade unit yielded the greatest fuel savings, 10.5%. The authors claim that savings could have been doubled if the the fan had been set to operate until outlet temperature reached 33°C (91°F) instead of 57°C (135°F). The potential for energy savings with flue gas heat recovery seems to increase with increasing flue gas temperature. That is, there is greater room for improvement in efficiency the more inefficient combustion is to begin with. For example, fuel savings were 6.5-6.7% for two houses with steady-state flue temperatures of 327°C and 393°C, while a savings were 2.7% in one house with flue temperature of 235°C.

It is important to note that little or no energy will be saved unless heat extracted from flue gas can be directed to areas of the house where heat is needed. Simply blowing hot air into an basement unused as a living area would not use all the recovered heat. Similarly, using recovered heat to heat an unheated crawl space or attic would totally waste the recovered heat.

Hoppe and Graves [21] found oil savings of 10% in oil-fueled boilers using flue gas heat reclaimers (see "Retention head burners" above). The installed cost in 1981 was $520.

The Alliance to Save Energy [22] claims that a secondary condensing water-spray type heat exchanger (figure 11) costs $600 to install on any fuel-

burning furnace and can save 25% of fuel use. Water is sprayed into the flue gases to recover heat. The water is then pumped to a fin-tube heat exchanger in the return air plenum, where it preheats air. The flue gas temperature is reduced to about 40°C (100°F) and can be safely vented through plastic pipe. Information on actual savings obtained in field tests are not reported.

4.7. Thermostat controls

4.7.1. Automatic boiler water temperature reset control

Automatic boiler temperature reset control allows for using a boiler water temperature which matches the amount of heat needed to maintain comfortable room temperature for a given outdoor air temperature. This controller automatically raises the circulating boiler water temperature setpoint as outdoor temperature drops, and reduces it in milder weather. Energy is saved due to reduced energy stored in the boiler, therefore less heat is lost out the stack during the off cycle. (This is particularly important in the absence of a stack damper.) Energy savings of approximately 10% have been reported. No additional energy was saved when installed on optimized flame retention head oil burners [21].

4.7.2. Setback room temperature thermostats

Setback room temperature thermostats allow different temperatures to be set for different times of the day or night.

Hoppe and Graves [21] found savings of 9% in oil-fueled boilers in houses using dual setback thermostats (see "Retention head burners" above). Houses were unoccupied during work hours. The installed cost was $80 for a one-zone house and $155 for a two-zone house. In combination with automatic boiler water temperature reset controls, savings were 18% at an installed cost of $390 to $425, depending on the number of zones (table 3). Single night setback of 3°C (5°F) is reported to save 7% of the gas used to heat a home [29].

4.7.3. Fan delay blower temperature control

Fan delay blower temperature control adjustment both after burner turn-on and shut-down can be optimized, without compromising comfort, to recover heat that would otherwise be lost out the stack. Gas savings of 6800 MJ/yr (64 therms/year) has been reported. Electricity use has been reported to typically increase by 610 MJ/year (170 kWh/year) since the blower motor must operate longer. However, with utility rates of $0.0066/MJ ($0.70/therm) for gas and $0.017 ($0.06/kWh) for electricity, savings amount to $35/year without need for any equipment, and minimal labor cost. (The adjustment can be accomplished on some units with a screwdriver, and on most units by moving a manual control dial.) Delay times corresponding to these savings were 40 seconds after burner startup, and 160 seconds after burner shutdown, or approximately 45°C (110°F) and 30°C (90°F), respectively, for the warm air supply.

4.7.4. Thermostatic radiator valves

A thermostatic radiator valve automatically controls the flow of steam or hot water to a radiator in response to a remote thermometer. This permits temperature control for individual rooms. Honeywell [30] claimed energy savings up to 35%, without reporting either field tests or laboratory simulation studies to substantiate any savings. Savings would undoubtedly vary with setback patterns.

4.8. Replacement furnaces and boilers

4.8.1. Forced-air furnaces

As mentioned previously, it may be more cost-effective to replace than to retrofit an old furnace or boiler. New equipment offers many more years of life at considerably higher efficiency than retrofitting. New forced-air gas furnaces with annual fuel utiliaztion efficiency (AFUE) in the mid-eighty percent range are advertized at prices below $1000, with average installed costs of $1300 to $1600 [31]. (See "A directory of certified furnace and boiler efficiency ratings" [32]. This directory is an annual publication which lists gas- and oil-fueled furnace and boiler AFUE by manufacturer and model number, and fuel input and heating capacity.) High-efficiency condensing forced-air furnaces with AFUE in the low to mid-ninety percent range would cost more than the Department of Energy limit of $1600 [3] for single-family home. Average installed cost for oil forced-air furnaces, whose AFUE is usually in the high seventy to low eighty percent range would be $1800 to $2000 [31].

4.8.2. Hot-water boilers

Prior to the introduction of high efficiency boilers in the late 1970's, average boiler efficiency was 45-55% [33]. Currently 80-85% AFUE is common. Average installed cost is $2500 to $2800 for a gas-fueled boiler with AFUE up to 87%. An oil-fueled boiler with 80-83% AFUE is reported to have an average installed cost of $1900-2200.

4.8.3. Determining energy savings from annual efficiency ratings of furnaces and boilers

A simplified calculation of energy savings can be done as follows. For each unit of energy supplied to the home, the energy into the furnace or boiler is 100%/AFUE.

$$\% \text{ energy savings} = 100 \times (100/AFUE_{\text{old furnace}} - 100/AFUE_{\text{new furnace}})$$

The AFUE of the old furnace is unknown but it can be estimated by testing combustion efficiency during continuous burner operation (i. e. steady-state efficiency). This should be done during normal maintenance and servicing of the unit.

AFUE may be estimated as steady-state efficiency less 10% for a gas furnace. This is based on a reference system with the difference between a steady-state efficiency of 75% and a part-load average seasonal system efficiency of 66% [29]. Another source [34] considers a reference gas furnace seasonal efficiency to be 60%. In general, a 15% difference would

be the more appropriate difference between these two efficiencies for older units in the field. For gas-fueled furnaces and boilers, the lower the initial system efficiency, the greater the potential energy savings. For example, improving system efficiency from 50% to 60% saves 20% of the energy, while improving it from 70% to 80% saves 14%, as discussed in section 4.1. Savings beyond the efficiency improvement can result from proper sizing. Oak Ridge National Laboratory [9] estimates that gas-fueled furnaces oversized by a factor of two require 8-10% more gas than properly sized furnaces. This calculation of energy savings does not take into account the electric energy used for the blower or other electric powered devices. (This amounts to perhaps an additional 5% of the annual cost of operation. However, its effect cancels out in comparison if one assumes that both old and new equipment use about the same amount of electricity.) A more detailed calculation of annual cost of operation based on geographical location, and a given design heating requirement is given in "A directory of certified furnace and boiler efficiency ratings" [32].

4.9. Electronic pilot ignition devices

Intermittent ignition devices ignite gas to begin the combustion on cycle, eliminating the need for a constantly burning pilot light.

Most older gas furnaces and boilers have a pilot burner in addition to the main burner. The pilot burner may be on all year, consuming fuel at a rate of about 300 W (1 cfh or 1000 Btu/h) [9]. The pilot burner supplies useful heat during winter but wastes fuel (about 5-10% of total annual consumption [9]) during the summer if it is not turned off (figure 4). In addition, it may impose an additional heating load on the air conditioner during summer.

The pilot burner ignites fuel at the main burner at the start of the on cycle. Intermittent ignition devices either replace pilot lights (direct spark ignition systems) or turn them on (pilot ignition systems) when there is a call for heat. Direct spark ignition systems are available only in new appliances, not as retrofits.

Most intermittent ignition devices, in conjunction with flame sensing devices (thermocouples, diastats or bimetals), also serve the additional safety function of shutting off the supply of gas to the main burners if ignition does not take place. Intermittent ignition devices operate much as spark plugs; a high voltage spark ignites fuel. When ignition is proven, a flame sensing element signals a control module, which stops sparking. Most intermittent ignition devices used for retrofits use an electronic flame ionization sensor to test for a flame [6]. If the flame is extinguished, the entire system is shut down. In the SHEIP study, gas savings in 24 houses using intermittent ignition devices were 4.4% (table 2) [12].

Energy savings depend on pilot size, total annual fuel use, and length of heating season. For example, for a typical pilot burner burning gas at the rate of 440 W (1500 Btu/h), fuel waste during a 5-month non-heating season (May-Septemper) would be 5700 MJ (54 therms) for a cost of $32/year at $0.0056/MJ ($0.60/therm). For a typical central heating system using 107,000 MJ/year (1000 therms/year), this would be an energy savings of 5.4%.

Retrofit of intermittent ignition devices is questionable. Energy savings may not justify expected installed cost of about $200 [35]. If the pilot is turned off during the non-heating season, intermittent ignition devices would save no additional fuel at all.

4.10. Insulating exposed duct work

Insulation of exposed ducts in unheated areas can reduce heat loss. Figure 4 shows the heat losses for a gas furnace system [9]. Uninsulated ducts passing through unheated crawl or attic spaces can lose heat at the rate of about 2.6 $W/m^2 \cdot {}^oC$ (1.5 $Btu/h \cdot ft^2 \cdot {}^oF$). This can amount to 40% of the heat output of a furnace [9], and may be the largest single source of waste in the heating system.

ANSI/ASHRAE Standard 90A [36] includes a section on minimum air-handling duct system insulation. This standard is based on the design temperature differential (T) between the ambient air temperature and the duct surface. The required R-factor is R = T/15 $ft^2 \cdot h \cdot F/Btu$.

Also see the NBS report "Recommended criteria for materials and products to be included in the DoE weatherization assistance program" [37].

4.11. Zone control

4.11.1. Radiator and warm air register covers

The Institute for Human Development [38] developed aluminized mylar, and more recently, aluminized fiberglass, radiator covers that can be used to selectively control radiators in a house, for example in unoccupied areas. For hot air systems, plastic cut to the size of air registers serves the same purpose. Water pipes located near heating pipes or ducts will not freeze if these retrofits are used. By contrast, it is difficult to selectively heat parts of heating zones with many modern systems, and if they were turned off in some zones, nearby water pipes might freeze.

To date, 193 of these retrofits have been installed in Philadelphia and its suburbs, and 20 in Minneapolis-St. Paul. The installed cost is less than $600, and preliminary results indicate that up to 40% reduction in fuel use can be achieved.

4.11.2. Thermostatic radiator valves (see 4.7.4.)

5.0. Water heating retrofit options

The typical energy consumption of a residential electric or gas water heater is about 22,000-30,000 MJ/yr (6000-7500 kWh/yr or 21,000-28,000 Btu/yr) [39, 40]. Thermal losses account for 30% of electric water heater energy losses, and 50% of gas- and oil-fired water heater energy losses [41, 42]. Standby losses are estimated to be 3200-4300 MJ/yr (900-1200 kWh/yr), or 15-20% of total energy consumption for standard residential water heaters, and 2950-3310 MJ/yr (820-920 kWh/yr), or 14-15%, for some commercially available energy saving water heaters [39]. The National Bureau of Standards [43] tested water heater energy conservation measures in nine water heaters for their ability to reduce these losses. The

measures tested were 1) reduced thermostat settings, 2) increased insulation, 3) intermittent ignition for gas-fired heaters, and 4) flue dampers for gas- and oil-fired heaters. The reported results are applicable to most, if not all, types of residential water heaters because most of these differ mainly only in heat source and storage volume [41]. Energy savings for combinations of these retrofit measures are shown in table 4.

In a computer simulation study, Oak Ridge National Laboratory [42] predicted energy savings due to various conservation measures for gas and electric water heaters. Table 5 lists energy savings and cost increases of various combinations of these measures. Using a combination of conservation measures that would raise the initial cost of a water heater by 26 or 27%, electricity consumption could be reduced about 17%, gas consumption could be reduced about 27% [42]. The conservation measures include increasing thickness and reducing thermal conductivity of jacket insulation, reducing thermostat setting, and adding insulation to the distribution pipe.

Below, individual energy conservation measures suitable for retrofit are described and their energy savings estimated.

5.1. Reduced excess dilution air

Reduced excess dilution air can result from reduced size of new water heater. See section 4.5.1 for a discussion of reducing excess dilution air by resizing the vent connector.

5.2. Reduced thermostat settings

Energy can be saved by reducing the water heater thermostat setting during normal operation, and by reducing the thermostat or turning off the heater altogether when the house is unoccupied. Since most thermostats are adjustable, this can be done by the owner. Lowering the thermostat can only be done if there is enough water available. This measure is more valid with gas than with electric water heaters because temperature recovery takes about twice as long in electric heaters. Lowering the thermostat reduces energy demand because less energy is required to heat a given volume of water, and because heat losses from the tank jacket, flue, exposed fittings and service connections are reduced. In homes without dishwashers or with dishwashers with inline water heaters, thermostats may be set as low as 50^{o}C (122^{o}F) [43]. Most dishwasher manufacturers recommend temperatures in the range 60-70^{o}C (140-160^{o}F).

Energy savings were about 12% for a thermostat setback of 10^{o}C (18^{o}F), from 70^{o}C (158^{o}F) to 60^{o}C (140^{o}F), in heaters with no extra insulation [43]. In another study of two electric heaters, (190 kWh/yr) was saved by reducing the thermostat setting 11.2^{o}C (20^{o}F), from 65^{o}C (150^{o}F) to 55^{o}C (130^{o}F) [44]. Savings were 9% for heaters with extra insulation [43]. ORNL [42] calculated energy savings of 5% for a thermostat setback of 5.6^{o}C (10^{o}F) on gas-fired and electric water heaters (table 5). There is no equipment cost increase [42].

5.3. Add-on tank insulation

Jacket losses are a major source of heat loss in water heaters. An insulated blanket may substantially reduce jacket losses [43].

Increasing the thickness of fiberglass insulation from 50 mm (2 in) to 75 mm (3 inches) saved 470-720 MJ/yr (130-200 kWh/yr) depending on tank size [44].

Extra insulation saved 7-9% of the energy used to heat water in standard heaters. Only 2.6% of the energy was saved in an energy-saving electric water heater that was originally insulated better than standard heaters. In the ORNL simulation [42] increasing jacket insulation from 5.1 cm (2 inches) to between 7.6 cm (3 inches) and 12.7 cm (5 inches) fiberglass insulation saved 4-7% of the energy needed for an electric water heater at an initial equipment cost increase of 4-12%. Increasing insulation from 2.5 cm (1 inch) to between 5.1 (2 inches) and 12.7 cm (5 inches) saved 7-11% for a gas-fired heater at an initial cost increase of 3-14% (table 5).

NBS Special Publication 606 [7] includes "Standard practice for the installation of thermal insulation in domestic water heaters."

5.4. Insulation of distribution pipe

ORNL [42] estimates that gas water heaters lose 3%, and electric heaters 5%, of their energy through the first 7.6 m (25 ft) of distribution pipe. ORNL estimates that 3% of the energy used to heat water can be saved by insulating this pipe, at an initial cost increase of 9-10% (table 5). Ontario Hydro [39] estimate that insulating short lengths of distribution pipe, 1.5-2.6 m (4.9-8.4 ft), above the tank, saved 270 MJ/yr (75 kWh/yr). The National Bureau of Standards [45] estimates that insulating pipes leaving water heaters can save energy at the rate of 4 W, or 125 MJ/yr (35 kWh/yr).

According to ANSI/ASHRAE Standard 90A [36], service water heating pipes up to 2.5 cm (1 inch) in thickness should be insulated with 1.25 cm (0.5 inch) of insulation.

5.5. Heat traps

Heat traps are curved sections of pipe, or check valves, that brake the natural tendency of heat to rise out of a water heater by both convection and conduction. Several types of heat traps are shown in figure 12 [46]. Ontario Hydro [39] measured energy savings on an energy efficient water heater. They estimate that commercially available copper heat traps can save 125 MJ/yr (35 kWh/yr), while experimental plastic heat traps can save about 360 MJ/yr (100 kWh/yr). Insulating short lengths of distribution pipe, 1.5-2.6 m (4.9-8.4 ft), above the tank, saved 270 MJ/yr (75 kWh/yr), while in combination with plastic heat traps, savings were 595 MJ/yr (165 kWh/yr). The National Bureau of Standards [46] estimates that for water 50°C (90°F) warmer than room temperature, insulating pipes leaving water heaters can save energy at the rate of 4 W, or 125 MJ/yr (35 kWh/yr); heat traps can save energy at a rate of 8 W or 250 MJ/yr (70 kWh/yr). These results indicate that far less energy can be saved when pipes are horizontal rather than vertical. This is because energy loss from

horizontal pipes is already lower than from vertical pipes. Horizontal pipe is an inherent heat trap. Its geometry discourages thermal convective flow.

5.6. Vent dampers

A vent damper installed on the water heater vent pipe acts to reduce the amount of heated room air lost out the stack more than it helps to reduce energy consumption by the water heater. Therefore, the use of a vent damper should only be considered where heat recovered at the water heater vent can be useful to heat the home. When the water heater is installed in unheated areas, there is little advantage to installing a vent damper. One type of damper that closes off both the flue and stack had been approved for manufacture but is presently not in production. That type is referred to as a mechanical damper. The most common type of vent damper applicable to gas fueled water heaters is the thermal damper, because water heaters do not have electric hook-up and thermal dampers do not require it. See figure 9 (a).

A rule of thumb is that if a vent damper has been installed at the furnace or boiler and if the heating system is installed in the same area as the water heater then the water heater vent should also be equipped with a vent damper.

See section 4.4 for additional discussion of vent dampers.

5.7. Combination Boiler/Water Heater (Tankless Coil System)

One type of water heating system which has not been included in figure 2 is the combination boiler/water heater; also referred to as the tankless coil type boiler. This system uses a heating coil immersed in the boiler to supply hot water on demand for showers, bathing, clothes washing etc. This type of water heater is very efficient during the winter months when space heating is also needed. However, during the non-heating season this system uses an inordinate amount of energy compared to storage tank water heaters. A new tankless coil system would be allowed, under ASHRAE Standard 90, a stand-by loss of roughly 3300 BTU/hr. (calculated based on typical assigned values for a family of 4) vs. 1500 BTU/hr. for a gas or oil fueled tank type, and 400 BTU/hr. for an electric tank type. During the non-heating season it would likely be more cost effective to install a tank type water heater and shut the boiler off. (See Figure 6.) Another advantage to using a separate storage tank has been reported in (47) which involved a field study of residential oil fired heating systems in New England. In that field study, it is reported "Reserve storage tanks were installed to satisfy the demand for hot water while the firing rate of the system was reduced to more nearly match the heating load of the residence." This resulted in an average space heating fuel savings of 13%. (See section 4.1.2.) If the add on tank were being considered for the benefits derived from derating the heating system, it would be possible to gain the additional benefit of a more efficient water heating system as well. An electric water heater tank could serve as the add-on tank during the heating season with the electric resistance heater turned off and using the boiler to heat water. During the non-heating season, the electric water heater would operate normally (with the resistance elements), with the boiler shut off. The cost effectiveness of this option would need to be

investigated since it would be controlled by the local utility rates, and the length of the non-heating season, and fuel used with the tank type heater.

6.0. Heat pump water heaters

Heat pump water heaters operate on a vapor-compression cycle similar to that of a window air conditioner. Heat is pumped from the air in the room surrounding the device into the water tank. Figure 13 shows an integral heat pump water heater and figure 14 shows an add-on heat pump water heater. Oak Ridge National Laboratory [48] tested 85 integral heat pump water heaters in homes. They estimated that heat pump water heaters use 12,020 MJ/yr (3339 kWh/yr), compared to 22,520 MJ/yr (6256 kWh/yr) for an electric resistance water heater, saving 47%, or 10,500 MJ/yr (2917 kWh/yr). This amounts to $145/year assuming an electricity cost of $0.18/MJ ($0.05/kWh). Oak Ridge estimates that heat pump water heater initially costs $600 more than a resistance water heater. Heat pump water heaters operated at an average cop of 1.9. There was no correlation between cop and regional climate. Cooler air temperature and noise were not a problem if the water heater were not too close to the living area.

7.0. Heat recovery from central air conditioners by desuperheaters

Heat recovery units that use waste heat from air-to-air heat pumps and central air conditioning systems to heat water are commercially available (figure 15). Heat from superheated refrigerant is transfered to water in a heat exchanger, and the heated water is stored in the hot water tank. Heat exchangers that can be used for retrofitting existing systems are available, as are complete systems for new installations [49].

Cooling performance is typically slightly improved. Heating output of a heat pump during the heating season is reduced approximately 20%, which means that the heat pump must run approximately 25% longer to satisfy the thermostat. In colder climates, the reduced heating capacity could result in cold supply air complaints, and longer defrost cycles. Therefore, it is common to open the electrical circuit to the hot water circulating pump with an outdoor thermostat set to open at 1.5-4.5^{o}C (35-40^{o}F) [50].

Several heat recovery units were tested by the National Bureau of Standards [49, 51] Some of the major conclusions are: 1) air-to-air heat pump performance is improved because of the decreased power required for the compressor; 2) hot water requirements cannot be met during the heating season by heat recovery alone; 3) there is little or no increase in operating costs; 4) heat recovery is most effective in areas, such as the southern United States, where air conditioning requirements are high. Energy savings are estimated to occur at rates of 90-135 W (800-1200 kWh/year) for four cities in different parts of the United States. This amounts to $40-60/year assuming electricity costs of $0.014/MJ ($0.05/kWh) [49].

Oak Ridge National Laboratory [52] compared energy use of desuperheaters (heat recovery units that use waste heat from air-to-air heat pumps or air conditioners) and electric resistance heaters in 115 United States cities. They found that during desuperheater use, consumption of electricity was only about 5% of the heat added to the water heater. The average homeowner

could expect to save in southern areas, about 66% of the electricity used for domestic hot water, and in northern areas, about 23% of the electricity.

The Florida Public Service Commission [53] sponsored a comparison study of 76 standard electric resistance water heaters, energy conserving electric resistance water heaters insulated according to ANSI/ASHRAE Standard 90A [36] (called "conventional" in the Florida Public Service Commission report), desuperheater water heaters, integral and retrofit heat pump water heaters, and solar hot water heaters in four different areas of Florida. Monthly coefficient of performance is shown in figure 16. It is clear that waste heat recovery and heat pump water heaters, in that order, have by far the highest coefficients of performance during the cooling season. Energy and dollar savings, and calculated return on investment are presented in table 6 (the average electricity cost is about $0.02/MJ ($0.07/kWh)). Energy and dollar savings, and costs, in decreasing order, were solar hot water heaters, heat pumps, desuperheaters, and conventional electric resistance heaters. Heat pump water heaters were found to be unreliable because of frequent compressor failure. The high coefficients of performance of waste heat recovery during the cooling season are so advantageous to utilities in reducing peak loading, however, that the authors suggest that utilites subsidize homeowners to install these devices.

Life-cycle costs of desuperheaters, heat pump water heaters and conventional gas-fired water heaters were compared for Minneapolis, Knoxville, and Tampa [52, 54]. Present value life-cycle costs were lowest for gas heaters in all cities ($1041-1443). Heat pump and desuperheater water heaters used about the same amount of electricity, and cost approximately the same over their lives ($1289-2749). It should be borne in mind that these costs were computed in 1979; the price assumed for gas was $0.00367/MJ ($0.387/therm or $3.87/mcf), and for electricity $0.0083-0.014/MJ ($0.03-0.05/kWh). (The highest electricity price was in Minneapolis.) As of June, 1983, gas cost $0.00623/MJ ($0.657/therm or $6.57/mcf) in Minneapolis, an increase of 70%, while electricity cost $0.019/MJ ($0.068/kWh), an increase of 14% [55]. Therefore gas lost some, if not all, of its relative cost attractiveness compared to electricity since the ORNL report. (If gas-fired water heaters operate at an efficiency of 50%, and electric water heaters at 75-80%, then in Minneapolis, electric air-to-water heat pumps would be more economical if their cop was above about 2, considering only energy costs.)

Arthur D. Little, Inc. [56] calculated that the payback period is two years for new factory installed units that recover heat from air-to-air heat pumps, three years for units that recover heat from air conditioners, and twice as long for retrofit devices. They assumed that in 1979 retrofit units cost $500 installed, factory installed units cost $250, and heat recovery rates are 17% of cooling rate and 0.08% of heating rate. Projected electricity savings range from a rate of about 120 W (1050 kWh/year) in the Pacific and New England states to 285 W (2500 kWh/year) in the West South Central states.

8.0. Maintenance

8.1. Central Air Conditioners

The Trane Company performed a study on an eight year old residential air conditioning unit [57]. The objective was to "determine the impact of wear and tear on the operating efficiency and cooling capacity of the old air conditioner that has received maintenance similar to many units presently owned and operated by homeowners." Their findings showed that a twenty percent improvement in efficiency could be achieved by a tune up. This included cleaning the coils (evaporator and condenser) and adjusting to the proper refrigerant charge. After replacing the coils and installing a new compressor, efficiency increased another twenty percent, mostly due to the compressor. Trane found that a ten percent drop in refrigerant charge caused efficiency to drop off by twenty percent.

The importance of proper refrigerant charge has been investigated in detail by the Texas Power and Light Company (Ref. [58]) in a labortory test of a 1.5 ton split system unit. The following is from their report: "Improper charging can best be defined as either a refrigerant overcharge or undercharge when compared with the manufacturer's charging specifications, at standard ARI rating conditions. Either condition will have a detrimental effect on the system, both in terms of equipment life expectancy as well as operating efficiency and economy.

"An undercharged condition will create abnormally high superheat which has an adverse effect on compressor motor winding cooling. The long term effect will be the eventual breakdown of motor winding insulation with premature compressor failure as a result. In extreme cases, due to the repeated opening of the internal motor overload protector, a much faster failure could occur.

From the operational standpoint, it is calculated that a refrigerant undercharge will cause the system capacity to decrease corresponding to the amount of undercharge. This is caused by a loss of refrigerating effect due to increased superheating of the refrigerant vapor."

Figure 17, entitled "Effect of Refrigerant Overcharge or Undercharge on System Performance Compared with Proper Charge," compares the effects, on system capacity and demand (kW), of a 23% refrigerant overcharge against proper charge.

"As illustrated by the curves in Figure 17, the undercharge condition affects the system operating efficiency and operating cost by causing a rapid decline in total capacity as the outdoor ambient increases, while at the same time the electrical demand (kW) is increasing at a slower rate. The resultant drop-off in system efficiency (EER) is very pronounced. The 23% by weight undercharge changed the EER from 8.31 to 5.49 at 95^{O}F. This is a 52% increase in operating cost. As a result, for this 1 1/2 ton unit, the annual operating cost can be expected to be increased by (1.23 kW x 1700 Hrs x $.07) = $133.63. In addition, the long term effect of elevated suction gas temperatures caused by this undercharged condition will reduce the life expectancy of the compressor. Some manufacturers claim this to be as much as 50%."

"The results of overcharge on system performance, as shown by the curves, is a slight increase in capacity over the proper charge but at a higher cost in terms of electrical demand (kW). As the outdoor ambient increases, the capacity and demand both approach an intersecting point with the proper charge curve."

"A refrigerant overcharge can reduce the life expectancy of a compressor due to the effects of liquid floodback, slugging, and motor overheating caused by abnormal head pressure and/or compression ratios."

8.2. Heating Systems

8.2.1. Oil Fueled Furnaces and Boilers

The subject of maintenance is most important for the oil fueled heating equipment because of the potential for efficiency degradation with poor combustion due to soot accumulation on the heat exchanger accompanied by reduced heat transfer and high flue gas temperatures. These effects are shown graphically in Bachrach Bulletin No. 4011 on Oil Burner Combustion Testing [59]. Field test results reported there show that initial smoke numbers greater than two (Bachrach scale) result in eventual rapid drop off in efficiency. An example of one test unit is given where an initial smoke reading of No. 5 resulted in an efficiency drop from 72% to 66% after one thousand hours of burner operation. That efficiency degradation would mean that 9% more fuel would be required at the start of the second year of operation if the furnace heat exchanger had not been cleaned. Causes of the problem are related to improper draft, improper adjustment of combustion air, poor mixture of fuel and air and improper combustion chamber size for the burner flame. A section titled "An understanding of oil fired heating systems" should be referred to in (Ref. [20]). Also included in that reference are "Equipment Installation and Adjustment Procedures" and "Heat Losses and Modifications to Improve Efficiency."

One consequence of poor maintenance described in detail in Ref. [20] is the possible need to replace turbulators (baffles) in steel tube boilers. Frequently, turbulators need replacement because of partial destruction after many years of service, or removal during previous boiler cleaning without replacement.

Turbulators reduce flue gas temperature and reduce heat loss. It is important to be sure there is adequate chimney draft before installing turbulators. The savings potential of a turbulator is listed in that reference as 5 percent, and the savings potential of a tune-up for systems that are regularly adjusted is about 3 percent.

NBS publication [7] includes a section on "Tune-up and Evaluation of Existing Burner." See Table 7 for details of the annual dollar saving to be expected by increasing steady state efficiency. The Bachrach Instrument Company [59] describes burner service and proper combustion test procedures.

8.2.2. Gas Fueled Furnaces and Boilers

Routine maintenance should include replacing filters, removing any scale that may have dropped onto the burners, cleaning dust, lint, etc. from the blower housing and motor, and lubrication of fans or other motors and pumps that require it (other than oilless bearing type).

Combustion checking of the unit with adjustment of the primary air supply to the burner is recommended. This should include checking the carbon monoxide to insure that it is not increased above the accepted level (not greater than 400 ppm air free is required for ANSI approval of furnaces and boilers). Many potentially hazardous situations can be found and corrected during a tune-up of the furnace. One of these is the possibility of a corroded heat exchanger that has developed a hole. Several methods of detecting a leaking heat exchanger are described in "Field Service and Adjustment of Gas Space Heating Equipment" [6]. These methods include comparison of the flame appearance with the blower off versus blower operating, smoke tests, salt tests, and odor tests. However, that reference states "the only reliable method that ensures that a heat exchanger is not leaking is a visual inspection of the exchanger." This requires dismanteling the appliance and is therefore time consuming. Field tests by seven gas utility companies have confirmed the superiority of a new method to detect leakage through furnace heat exchangers [60]. The method involves the injecting a special tracer gas mixture at the burner side of the heat exchanger and measuring for leakage on the air side using a calibrated detecting meter. Since major retrofitting is also costly, it is strongly recommended that if a furnace heat exchanger is older than 10-15 years that an inspection or testing be made before expending the money and effort to do a major retrofit of the unit. A major retrofit is considered to be derating, or installation of a heat extractor; electric ignition and vent damper.

The most significant common problem reported [6] for hydronic heating is scale formation in the steam and condensate water passageways. These deposits can obstruct water flow and decrease heat transfer. See (Ref. [6]) for further details of the fundamentals involved in field service and adjustment of gas heating equipment. The Bachrach Company's "Gas Burner and Combustion Testing" Bulletin 4006 outlines the fundamentals of gas burner combustion and reviews testing and tune-up techniques (Ref. [61]).

8.3. Water Heaters

Degradation of energy efficiency over time in gas fueled water heaters is due mainly to insulating layers of scale on the tank bottom and walls, burner malfunction or misadjustment, and degradation of the heat transfer. This latter degradation can result from baffle deterioration, rust and soot accumulation in the flue, and flue blockage [62].

NBS studied the mechanism of gas-fueled water heater degradation by examining 26 used water heaters from different parts of the United States [62]. The operating life of water heaters is related to the total dissolved solids content of the water supply and temperature (Refs. [63] and [64]).
The corrosion rate doubles for every 11^{o}C (20^{o}F) rise in temperature. The principal cause of failure of gas-fueled water heaters is

corrosion induced leakage. Most water heaters are protected against corrosion by a glass lining and a sacrificial magnesium anode, which is preferentially attacked, protecting the tank. After the anode disintegrates, however, there is no further protection.

Many of the helpful hints on saving energy state that in order to prevent these deposits from building up that the homeowner should drain off water from the tank periodically. However, that energy saving hint is not effective in removing scale and deposits from the bottom of a tank because the drain valve is always a few inches above the tank bottom. The only effective way to remove these deposits is with a special chemical cleaning solution. (66)

Combustion testing of fossil fueled water heaters is also recommended. The same combustion test methods and procedures described in references in section 8.2 also apply to water heaters.

Also "Guidelines for Adjustment of Atmospheric Gas Burners for Residential and Commercial Space Heating and Water Heating" [67] is a publication that includes detailed adjustment procedures to minimize air pollution and to achieve efficient use of gas.

9.0. Standards

The following standards are believed to be the most current, however these may be revised following publication of this report. Some of the retrofit procedures cited in this report are not covered specifically by installation standards. In some instances, the referenced standard may or may not be in conformance with local codes. Local code officials should be consulted.

9.1. Space Heating System Retrofit

Retrofit Product or Procedure	Standards
1) Installation of Gas Conversion Power Burners (for Gas or Oil Fired Systems)	In conformance with, or latest, ANSI Z21.8a, ANSI Z21.17 and Installation ANSI Z223.1 - 1980 AGA Laboratories Certification Seal
2) Replacement Oil Burner	ANSI Z96.2 (UL 296) ANSI Z91.2 NFPA 31-1983
3) Power Burners (Oil/Gas)	Conformance to ANSI Z223.1, National Fuel Gas Code; ANSI Z83.1 Gas Installations; NFPA 31 Oil Equipment
4) Furnaces, Oil	Installation of Oil Burning Equipment, NFPA 31-1976
5) Furnaces, Gas	Gas Fired Central Furnaces, ANSI Z21.47 - 1978
6) Boilers	Boiler and Pressure Vessel Code (eleven sections) ASME 1980 or latest Testing and Ratings Hydronics Institute (HYDI)
7) Reduced Input of Burner, Derating	
(a) Gas Fueled	In conformance with Local Utility Company Procedures if applicable for gas fueled furnaces.
(b) Oil-Fired	EPA 600/2-75-069-9 "Guidelines for Residential Oil Burner Adjustments" Conformance to NFPA 31-1983, Standard for the Installation of Oil Burning Equipment

8) Replacement Combustion Chamber, in Oil-Fired Furnace, Boiler....	Conformance to NFPA 31-1983
9) Gas Fueled Heating Systems, Vent Dampers........................	Conformance with applicable sections, National Fuel Gas Code including Appendices H, I, J and K ANSI Z21.66 - 1977 and Addenda A and B for Electrically Operated Dampers ANSI Z21.68 - 1978 and Appendices A and B for Thermally Activated Vent Dampers ANSI Z21.67 - 1978 and Appendices A and B for mechanically actuated vent dampers
10) Oil Fueled Systems, Vent Dampers..	Conformance with applicable sections of NFPA 31-1983 for installation and in conformance with UL 17
Reduce Excess dilution air:	
(a) Reduction of Vent Connector Size of Gas Fueled Appliances..................	See Part 9 of ANSI Z223.1 - 1980 and Appendix G and H
(b) Adjustment of Barometric Draft Regulator Oil Fuels....	NFPA 31-1980 for Oil Fueled and per manufacturers' (furnace and burner) instructions
11) Replacement of constant burning pilot with electric ignition device on gas fueled furnaces or boilers........................	ANSI Z21.7-1981
12) Duct Insulation..................	See NBS Recommended Criteria (Ref. 7)
Pipe Insulation..................	Table 3 for Thermal Insulating Materials. Also see ASHRAE Standard 90A-1980 Section 5 (Ref. 36)
13) Clock Thermostats................	Conformance to NEMA[1] DC 3-1978 or NEMA DC 15-1979 and performance test requirements2

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[1] NEMA indicates National Electrical Manufacturers Association.

[2] The performance tests requirements are: (1) the operating differential should not exceed 2oF, and (2) the effective operating drop should not exceed 4oF when determined according to the applicable procedures in DC 3-1978 and DC 15-1979.

9.2 Water Heating

9.2.1 New Products

Retrofit Product or Procedure	Standards
1) Heat Pump Water Heaters	Listed by Underwriters Laboratories Standard for Electric Water Heaters Under Development by ASHRAE Efficiency Certification per Gas Appliance Manufacturers Association (GAMA) or Air Conditioning and Refrigeration Institute (ARI)
2) Oil, Gas, and Electric Water Heaters	Efficiency certification per GAMA. ASHRAE Standard 90A-1980 for guidelines on minimum performance required for recovery efficiency and standby loss
3) "Desuperheater/Water Heaters"	Conformance to ARI 470-80 Conformance to ARI 1060-80

9.2.2 Retrofits

Retrofit Product or Procedure	Standards
1) Insulate Tank and Distributing Piping	NBS Report on Criteria for Insulation, also see ASHRAE 90A-1980 - Section 7 on Service Water Heating
2) Install Heat Traps on Inlet and Outlet Piping	Applicable local plumbing code
3) Install Stack Damper, Gas Fueled	ANSI Z21.68, 1978 ANSI Z21.67, including addendas A and B ANSI Z223.1 - 1980
4) Install Stack Damper, Oil Fueled	UL-17 NFPA 31-1983

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68. [figure]W. P. Levins, "A comparison of laboratory and field test measurements of heat pump water heaters," presented at the ACEEE 1982 Summer Study, Santa Cruz, CA, August 21-28, 1982.

Table 1-A Method of reducing energy losses for heating systems (from Ref. 5)

- On-Period Losses

  Factors that influence steady-state losses and efficiency

  - burner excess-air level
  - flue-gas temperature
  - jacket losses
  - source and temperature of combustion air

  Other factors involved during the on period during intermittent operation

  - system load
  - cycle length
  - thermal mass of the furnace/boiler and heating medium

- Off-Period Losses

  - air flow through the burner and heat exchanger
  - system load
  - cycle length
  - thermal mass of furnace/boiler and heating medium.

Table 1-B Design routes to high seasonal efficiency (from Ref. 5)

1. Low-excess-air operation
2. Efficient heat exchanger
3. Reduction of burner oversizing
4. Reduction of off-period losses
5. Reduction of jacket losses
6. Reduction of furnace/boiler-induced air infiltration.

Table 2. Gas conservation potential of various retrofit options (from Ref. 12)

Type Of Retrofit Group	Sites Nos.	Group-Mean Gas Consumption Reduction %	± One Standard Deviation or at 70% Confidence Level	± Two Standard Deviations or at 95% Confidence Level
1 D(F+C) *	105	6.2	5.2 - 7.2	4.2 - 8.2
2 D(F+C)+VR	131	9.1	8.4 - 9.8	7.7 - 10.5
3 D(F+C)+IID	2	6.7	(-5.2) - 18.6	(17.1) - 30.5
4 D(F+C)+VD+VR+IID	50	12.6	1.09 - 14.3	9.2 - 16.0
5 D(F)	97	1.5	0.8 - 2.2	0.1 - 2.9
6 D(F)+VR	19	2.4	1.3 - 3.5	0.2 - 4.6
7 D(F)+IID	--	--	--	--
8 VD	146	5.1	4.5 - 5.7	3.9 - 6.3
9 VD+IID	122	5.1	2.7 - 6.3	3.7 - 6.5
10 VD+VD+IID	31	11.3	9.4 - 13.5	7.5 - 15.1
11 VR	35	3.7	2.4 - 5.0	1.1 - 6.3
12 VR + VR	34	7.7	5.9 - 9.5	4.1 - 10.5
13 IID	24	4.4	2.5 - 6.3	0.6 - 8.2
14 FHE	52	3.0	2.2 - 3.8	1.4 - 4.6
15 OA	41	-0.6	(-1.6) - 0.6	(-2.6) - 1.6
16 NS	13	4.9	2.0 - 7.9	(-0.9) - 11.8

* SYMBOL	DEFINITION
D	Derating
F + C	Fuel and Combustion Air
F	Fuel Only
IID	Intermittent Ignition Device
VD	Automatic Vent Damper
VR	Fixed Vent Restrictor
VD + VD	Double Damper (one for furnace, the other for water heater)
VR + VR	Double Vent Restrictor (one for furnace, the other for water heater)
FHE	Flue Heat Extractor
OA	Outside Air Connection
NS	Night Setback Clock

Table 3. Oil conservation potential of various retrofit options
(from Ref. 21)

OPTION DESCRIPTION	PROBABLE INSTALLATION/ SERVICE REQUIREMENTS (SEE LEGEND)	* 1980 INSTALLED COST $	FUEL SAVINGS % TYPICAL	FUEL SAVINGS % VARIATIONS
o BOILERS REFITTED WITH FLAME RETENTION HEAD BURNERS (RHB)				
RHB-ROUTINE REFIT	(1) (2) (5)	325	11	7-15
RHB-OPTIMIZED REFIT	(1) (2) (5)	390-425	18	16-22
RHB-OPTIMIZED REFIT & AUTOMATIC BOILER TEMPERATURE RESET CONTROL	(1) (2) (5) (3) (5)	665-700	20	15-24
RHB-OPTIMIZED REFIT & VENT DAMPER (TIMED DELAY, NO BYPASS)	(1) (2) (5) (1) (3) (5)	685-720	20	16-27
o BOILERS REFITTED WITH OPTIONS NOT INCLUDING A BURNER REPLACEMENT				
VENT DAMPER-(TIMED DELAY, NO BYPASS)	(1) (3) (5)	295	9	6-23
FLUE GAS/WATER HEAT RECLAIMER	(4) (3) (5)	520	10	4-17
AUTOMATIC DUAL SET-BACK THERMOSTAT(S)	(3) (6) (5)	80-155	9	4-14
AUTOMATIC DUAL SET-BACK THERMOSTAT(S) & AUTOMATIC BOILER TEMPERATURE RESET CONTROL	(3) (6) (5) (3) (6) (5)	355-430	19	10-32

LEGEND:

[1]Annual cleaning and adjustments are recommended to assure optimized equipment performance.

[2]Adjustments, cleaning, repairs, or replacement is generally provided at no additional cost by paid annual service agreements with the homeowner and fuel supply/service company.

[3]Adjustments, repairs, or replacement is generally provided by a separate time and material cost agreement after warrantee period.

[4]Cleaning and adjustments are probably needed to frequently optimize the efficiency of the equipment.

[5]Homeowner education, direct inputs, and adjustments are required for successful operation and maximum fuel savings.

[6]Local code authorities may require installation inspection fees.

*Cost will vary significantly with market area, the marketer, and product brand.

Table 4. Energy conservation potential of various water heater retrofit options. (from Ref. 43)

Modification	Reduction in Water Heating Energy Requirements[A] - %		
	Electric	Gas	Oil
Reduce thermostat setting by 10°C	11, (9)	13	12, [12]
Add 33 mm extra insulation	7, (3)	7	9, [9]
Reduce thermostat setting and add extra insulation	(11)	18	19
Replace original insulation with improved insulation of the same thickness	4	3	2
Replace original insulation with improved insulation of increased thickness	9	10	--
Reduce pilot input rate from 200 W to 60 W	-	1,2	--
Replace pilot with intermittent ignition	-	4,6,(3)	--
Replace pilot with intermittent ignition and add mechanical flue damper	-	11,16,(10)	--
Add a thermal flue damper	-	3, (2)	--
Add a mechanical flue damper	-	-	[14][B]

A - Parentheses ( ) indicate results for energy conserving models, brackets [ ] indicate results for external-flue water heater

B - Assumes a damper with zero leakage installed at the flue

Table 5. Energy conservation potential of various water heater design changes (from Ref. 42)

	0.19 m^3 (50 gal) Electric		0.15 m^3 (40 gal) Gas	
	% Energy Savings	% Cost Increase	% Energy Savings	% Cost Increase
1. Increase jacket insulation to				
a) 5.1 cm fiberglass			7	3
b) 7.6 cm fiberglass	4	4	10	6
c) 10.2 cm fiberglass	7	8	10	10
d) 12.7 cm fiberglass	7	12	11	14
2. Reduce jacket insulation thermal conductivity				
a) 2.5 cm urethane			9	4
b) 5.1 cm urethane	8	6	12	8
c) 7.6 cm urethane	10	11	13	10
d) 10.2 cm urethane	11	14	13	13
e) 12.7 cm urethane	11	17	13	16
3. Reduce thermostat setting 5.6°C	5	0	5	0
4. Add insulation to 7.6 m of distribution pipe				
a) 1.3 cm fiberglass	3	9	3	9
b) 2.5 cm fiberglass	3	10	3	9
5. Reduce pilot rate from 6.9×10^9 J/yr (218.8 W) to 3.7×10^9 J/yr (117.3 W)			6	0
6. Eliminate pilot — add electric ignitor and flue closure			12	84
7. Reduce excess air for combustion			3	1
8. 2d, 4b	14	24	16	23
9. 2e, 3, 4b	17	27	18	25
10. 2d, 4b, 5, 7			24	23
11. 2e, 3, 4b, 5, 7			27	26
Baseline	23.9×10^9 J/yr	$157	37.7×10^9 J/yr	$168

Table 6. Calculated annual energy and dollar savings and rate of return for four different water heating systems in Florida (from Reference 53)

6-A. Calculated Annual Energy Savings (kWh) per System for 3 Daily Hot Water Amounts

Conventional Electric			Heat Pump Water Heater			Solar Hot Water System			Waste Heat Recovery Unit		
40 Gal	55 Gal	70 Gal	40 Gal	55 Gal	70 Gal	40 Gal	55 Gal	70 Gal	40 Gal	55 Gal	70 Gal
345	476	605	1365	1878	2389	1838	2528	3217	925	1273	1619

6-B. Calculated Annual Dollar Savings per System for 3 Daily Hot Water Amounts

Conventional Electric			Heat Pump Water Heater			Solar Hot Water System			Waste Heat Recovery Unit		
40 Gal	55 Gal	70 Gal	40 Gal	55 Gal	70 Gal	40 Gal	55 Gal	70 Gal	40 Gal	55 Gal	70 Gal
24.33	33.57	42.67	96.27	132.46	168.50	129.63	178.30	226.90	65.24	89.78	114.19

6-C. Annual Rate of Return

	Cost	Annual Rate of Return(%)		
		40 Gal	55 Gal	70 Gal
Conventional Electric	$300	8	11	14
Heat Pump Water Heater	900	11	16	20
Solar Hot Water System	1350	10	13	17
Waster Heat Recovery Unit	650	10	14	18

Table 7. Annual Dollar Savings for $100 of Annual Fuel Cost as a result of Increased Furnace Efficiency*
(from Reference 7)

From original efficiency* of (Percent)	To an increased efficiency of (percent)						
	74	76	78	80	82	84	86
50	$32.40	$34.20	$35.90	$37.50	$39.00	$40.50	$41.90
52	29.70	31.60	33.30	35.00	36.60	38.10	39.50
54	27.00	28.90	30.80	32.50	34.10	35.70	37.20
56	24.30	26.30	28.20	30.00	31.70	33.30	34.90
58	21.60	23.70	25.60	27.50	29.30	31.00	32.60
60	18.90	21.10	23.10	25.00	26.80	28.60	30.20
62	16.20	18.40	20.50	22.50	24.40	26.20	27.90
64	13.50	15.80	17.90	20.00	22.00	23.80	25.60
66	10.80	13.20	15.40	17.50	19.50	21.40	23.30
68	8.10	10.50	12.80	15.00	17.10	19.00	20.90
70	5.40	7.90	10.30	12.50	14.60	16.70	18.60
72	2.70	5.30	7.70	10.00	12.20	14.30	16.30
74		2.60	5.10	7.50	9.80	11.90	14.00
76			2.60	5.00	7.30	9.50	11.60

*Efficiency is the steady state efficiency measured from the flue gas temperature and CO_2 or Oxygen concentration.

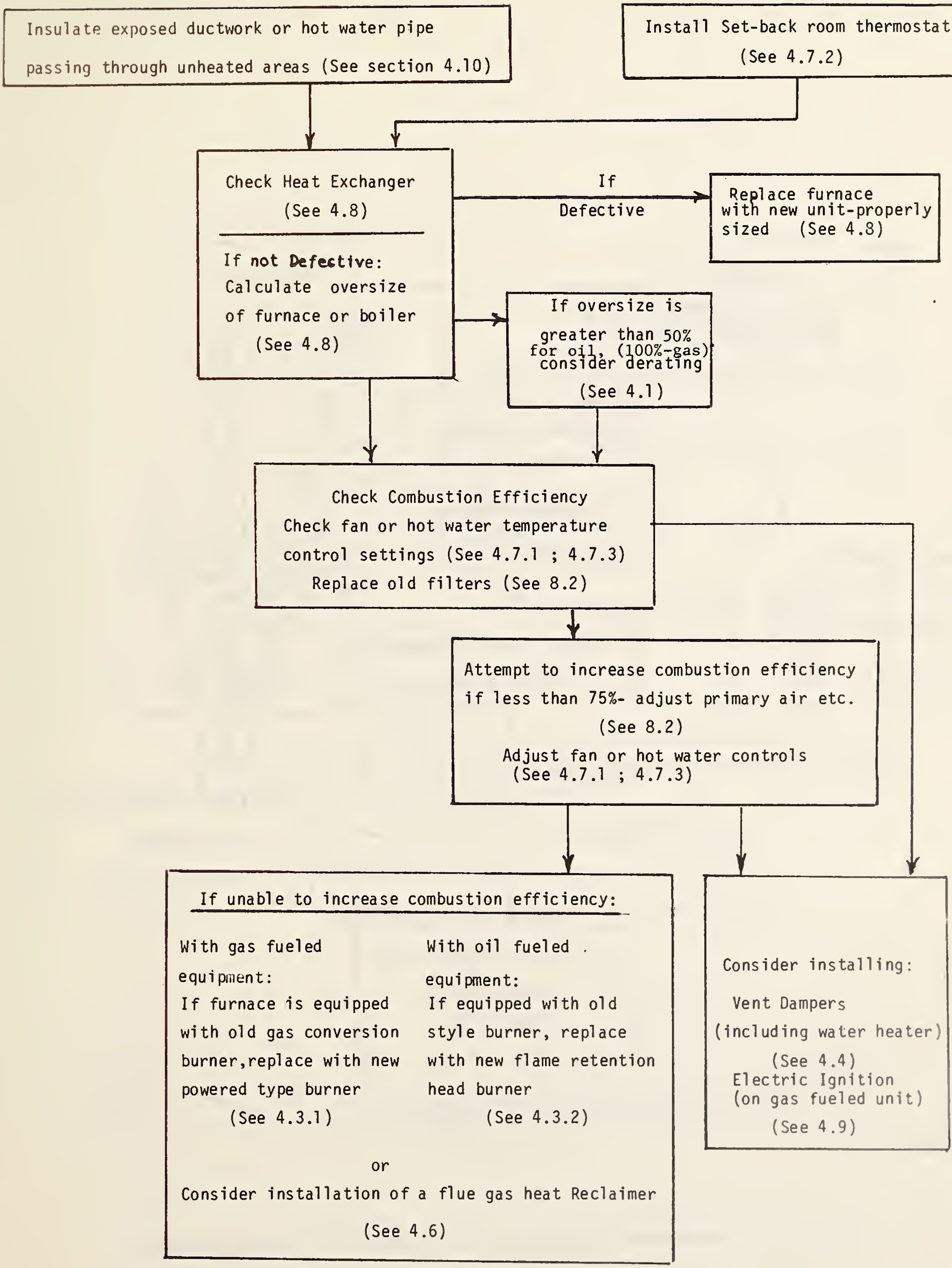


Figure 1. Recommended Approach for Retrofit of Space Heating Systems

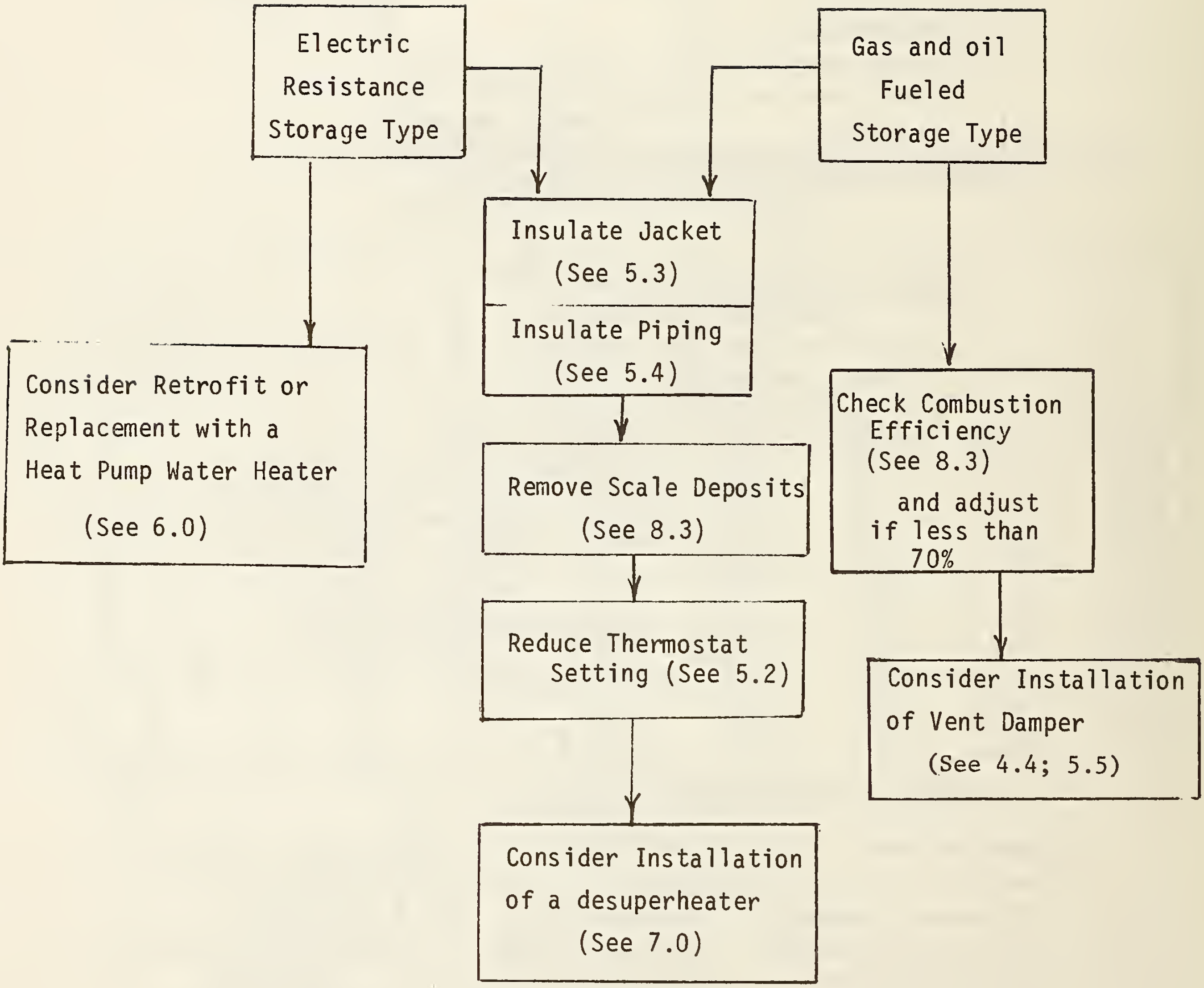


Figure 2. Recommended approach for retrofit of water heaters

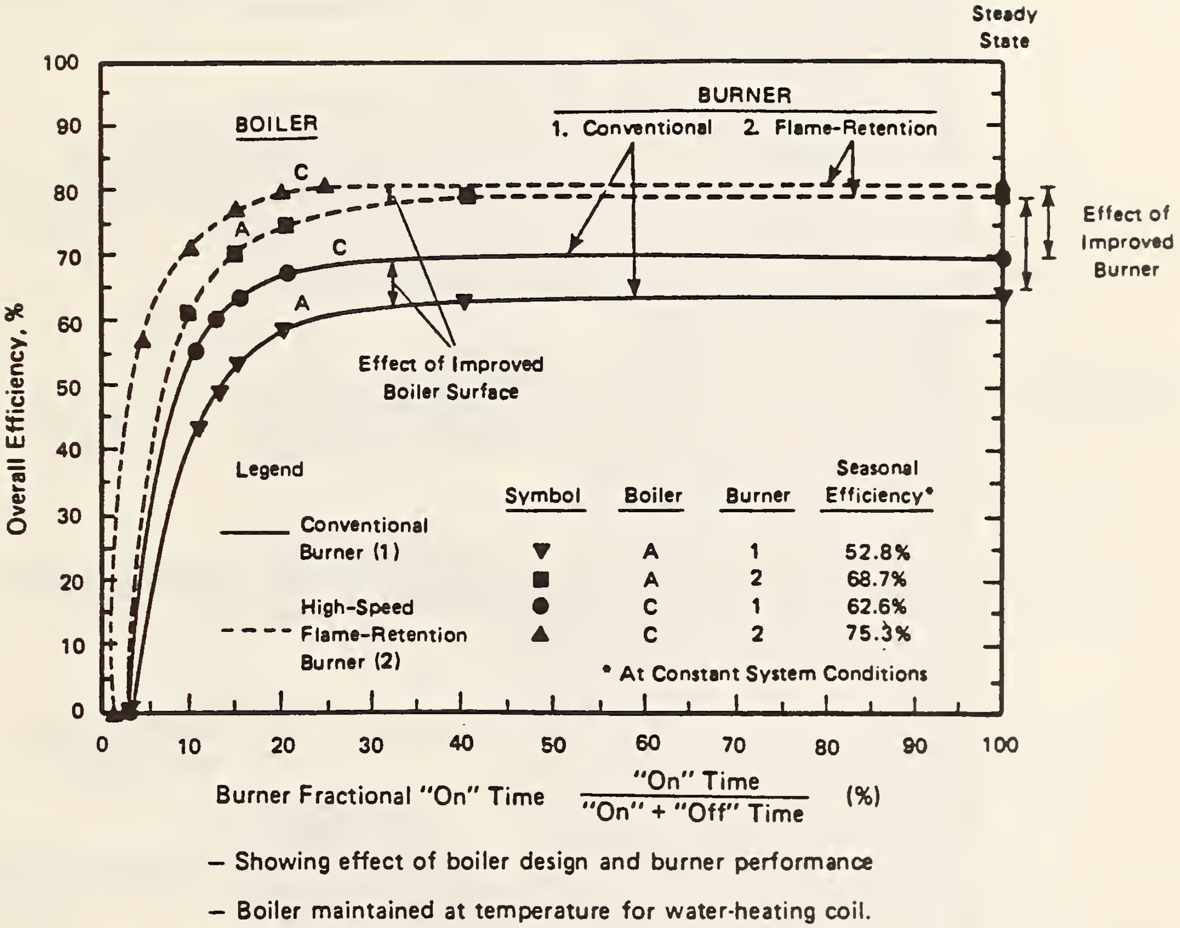


Fig. 3. Part-load efficiency in direct input/output tests (from Reference 5)

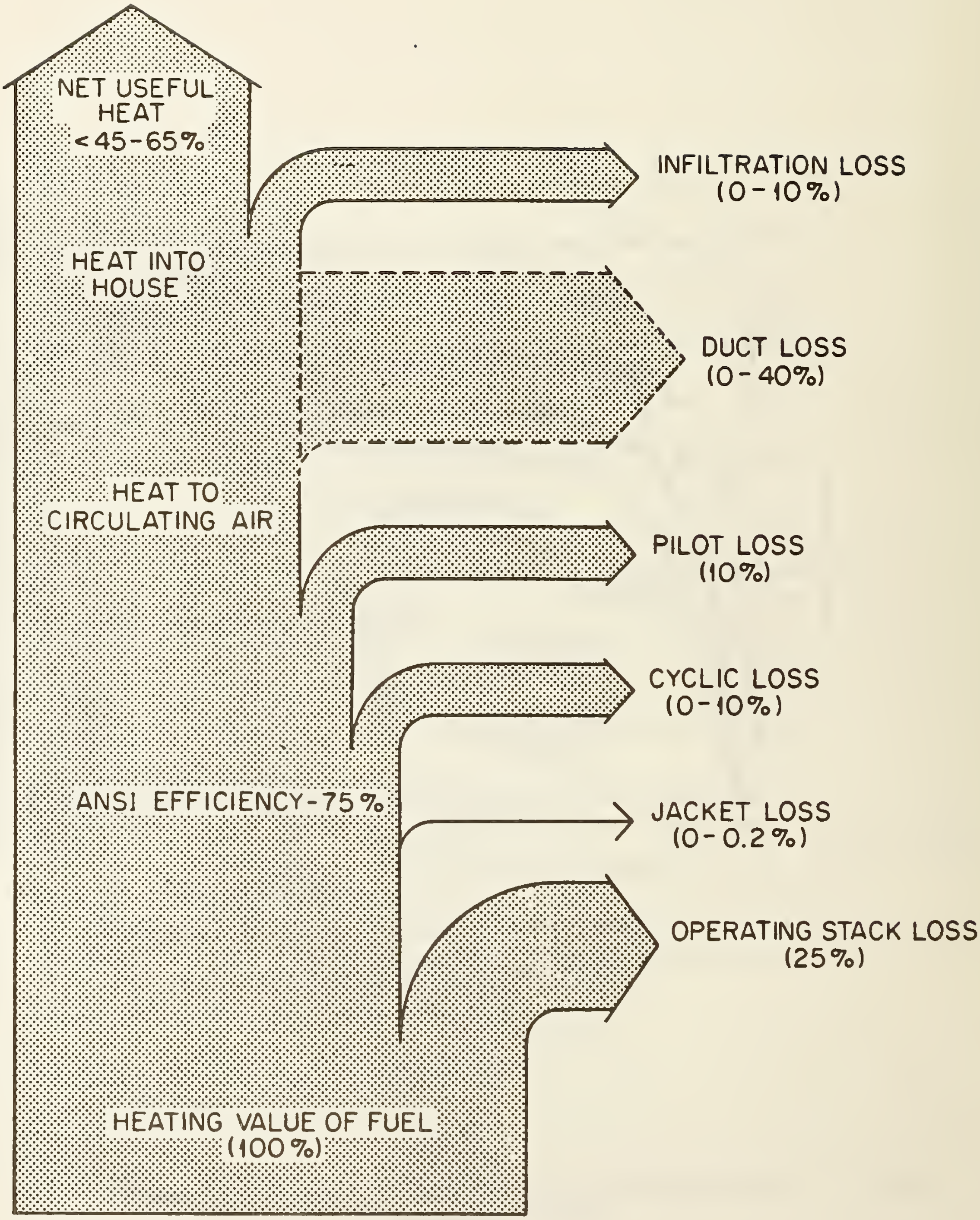


Fig. 4. Energy flow diagram for a gas furnace system (from Reference 9)

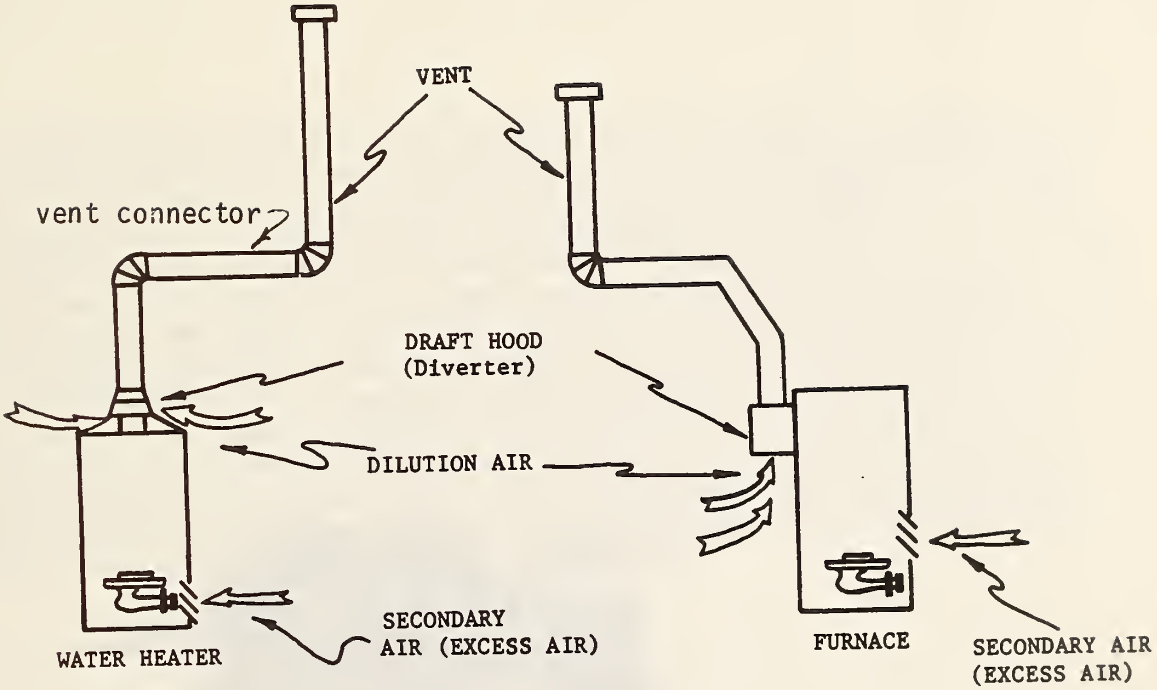


Fig. 5. Schematic of air supply and venting in furnace and water heater
(from Refrence 6)

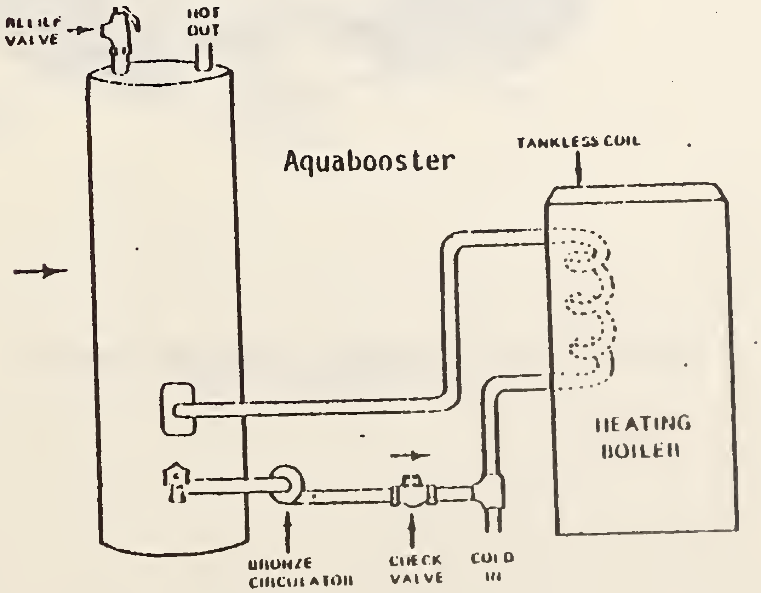


Fig. 6. Schematic of aquabooster water heater
(from Ref. 18)

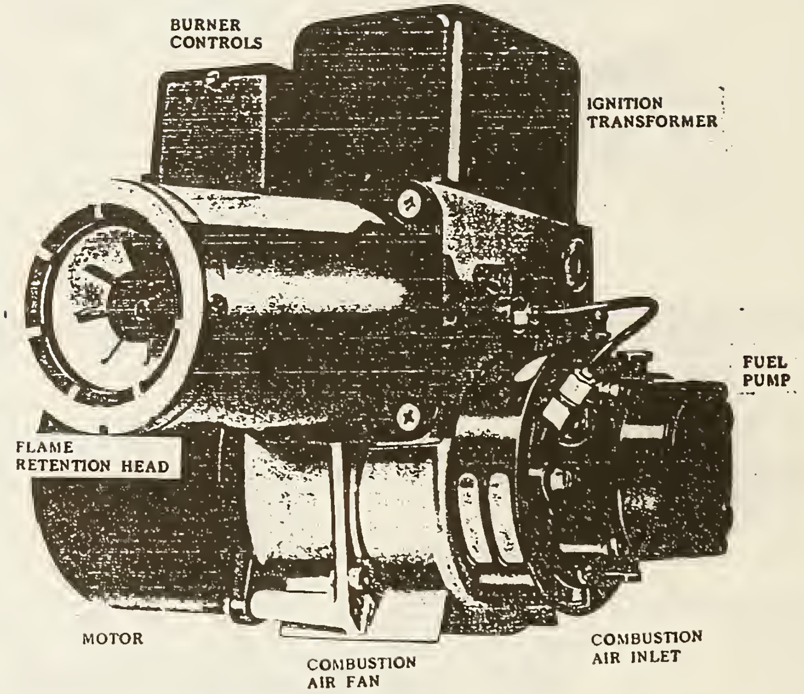


Figure 7. <u>Flame Retention Head Oil Burner</u>
(from Ref. 48)

A direct measurement method has been proposed as a potential alternative to the tracer gas technique now used to measure off-period energy loss of space heating equipment because the alternative does not require expensive tracer gas instrumentation. The method uses a controlled flow of gas to a small gas fuel burner to simulate normal flue or stack temperatures previously measured during a cool-down test. Energy metered through the gas burner during the simulation gives a direct measurement of the thermal energy losses out of the stack. The tests made to evaluate the method indicate that the simulated temperature vs time profile usually results in a lower value of off cycle energy loss than a normal cool-down while the measurement of the BTU's required for the simulation (bunsen burner fuel use) was eratic but frequently resulted in a larger energy loss evaluation. Further development testing and evaluation will be required before the simulation system can be considered as an acceptable alternative test method.

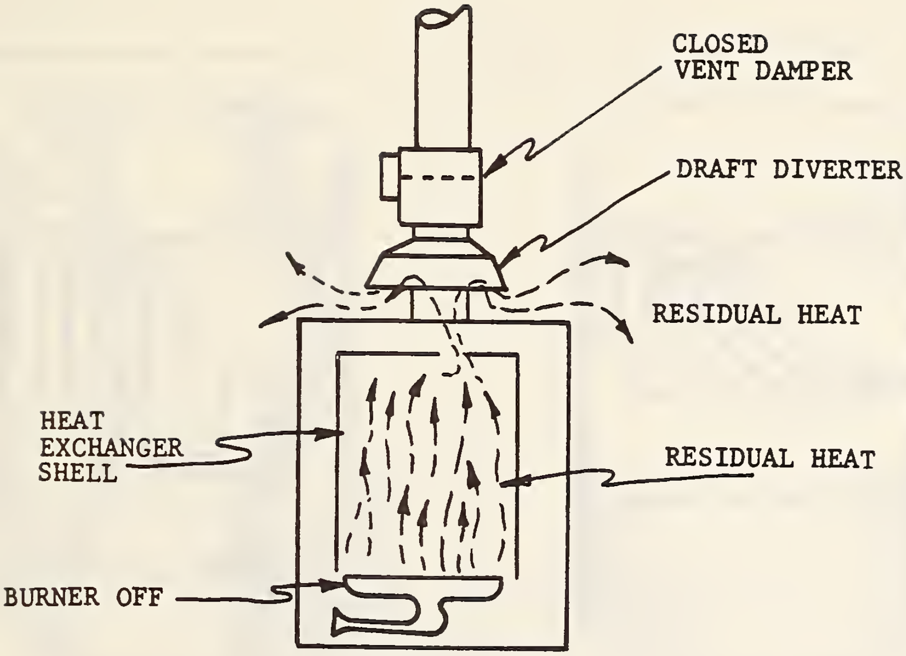


Fig. 8-a. Diagram of a boiler with vent damper
(from Ref. 6)

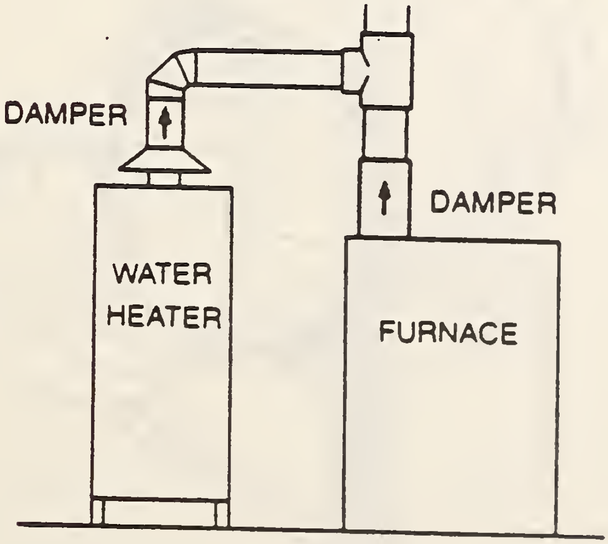


Fig. 8-b. Diagram of a common manifold vent damper installation
(from Ref. 6)

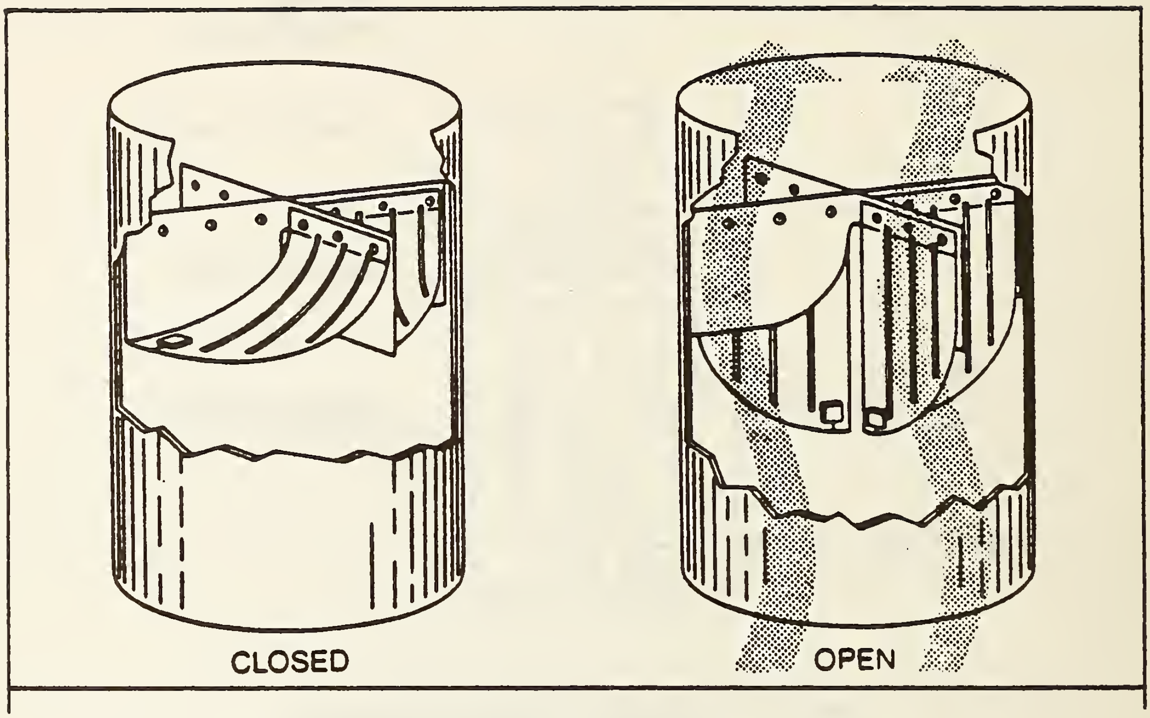


Fig.9-a. Diagram of a thermaly actuated vent damper
(from Ref. 22)

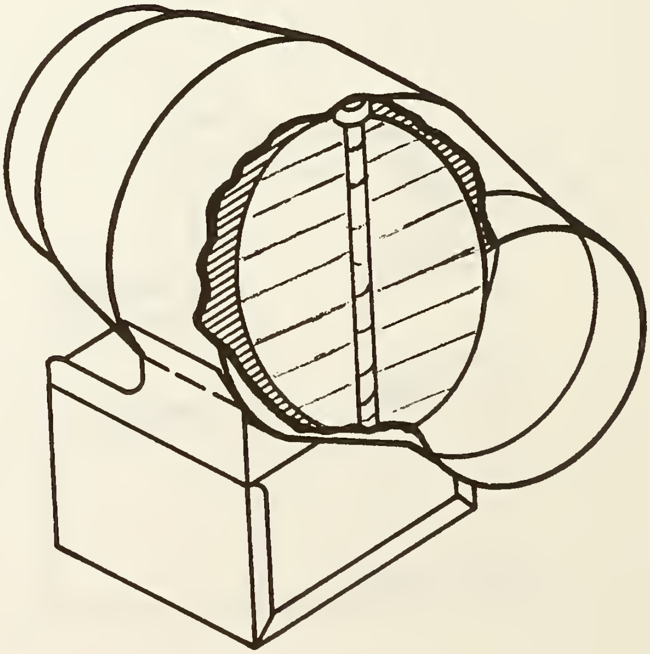


Fig.9-b. Diagram of an electric vent damper
(from Ref. 6)

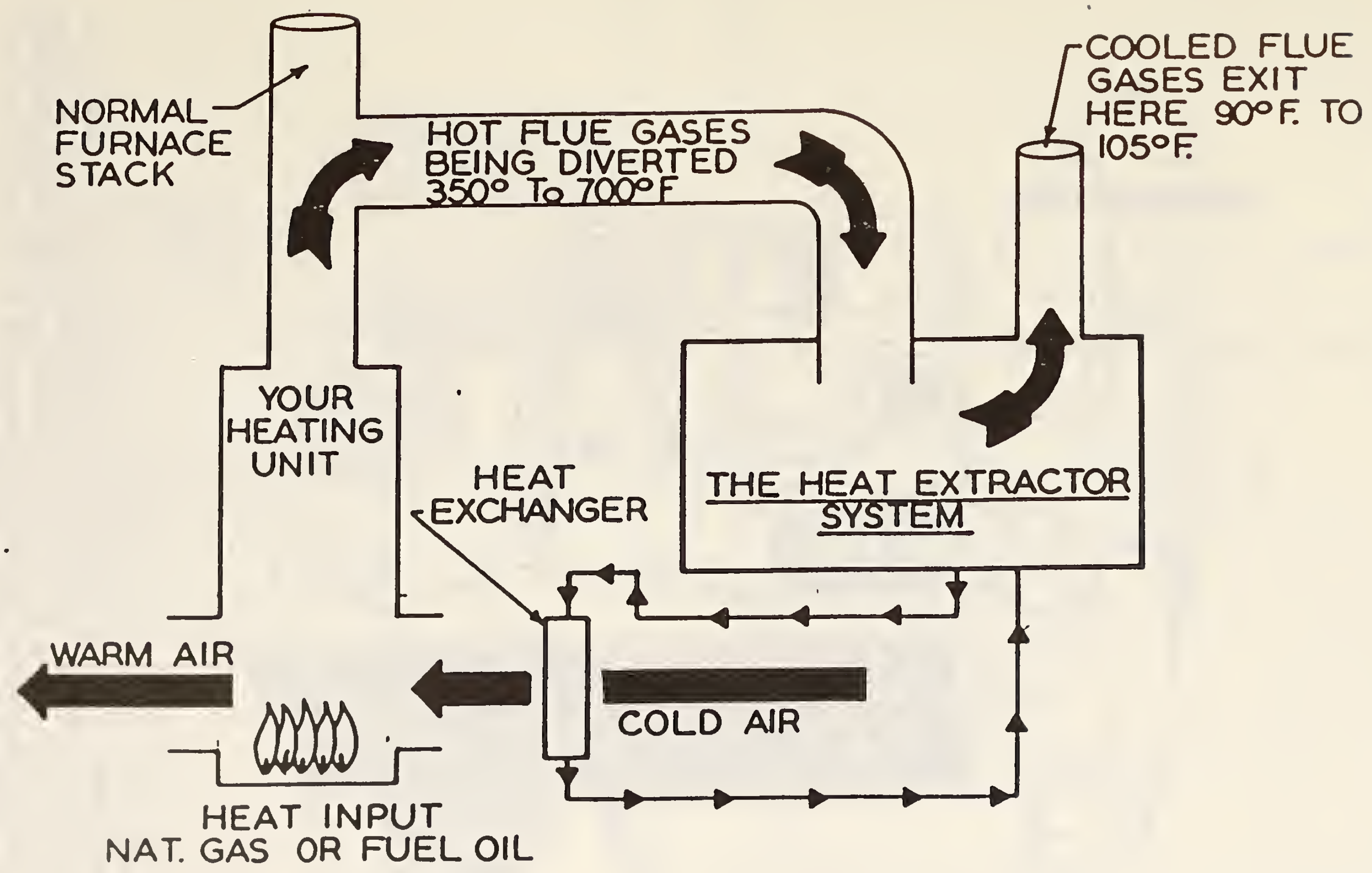
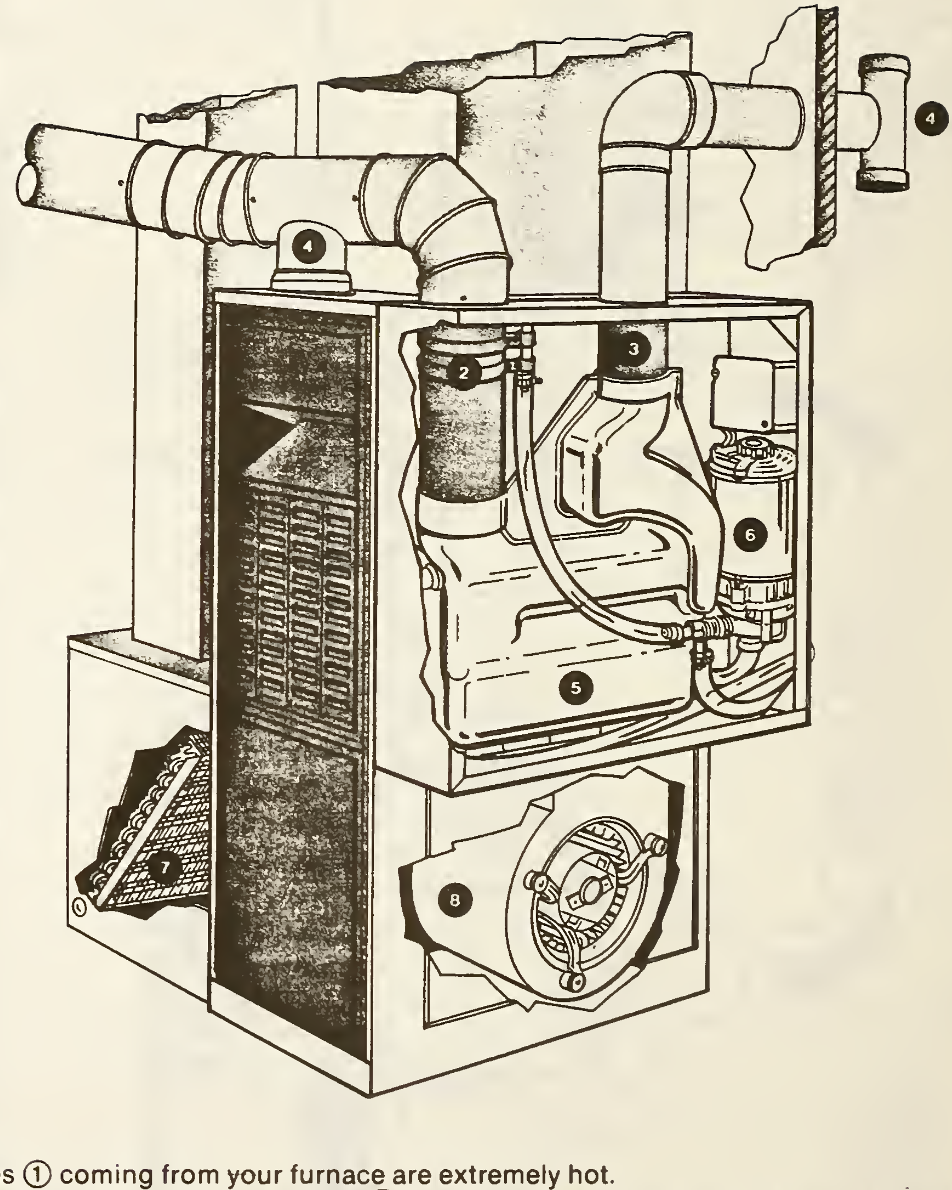


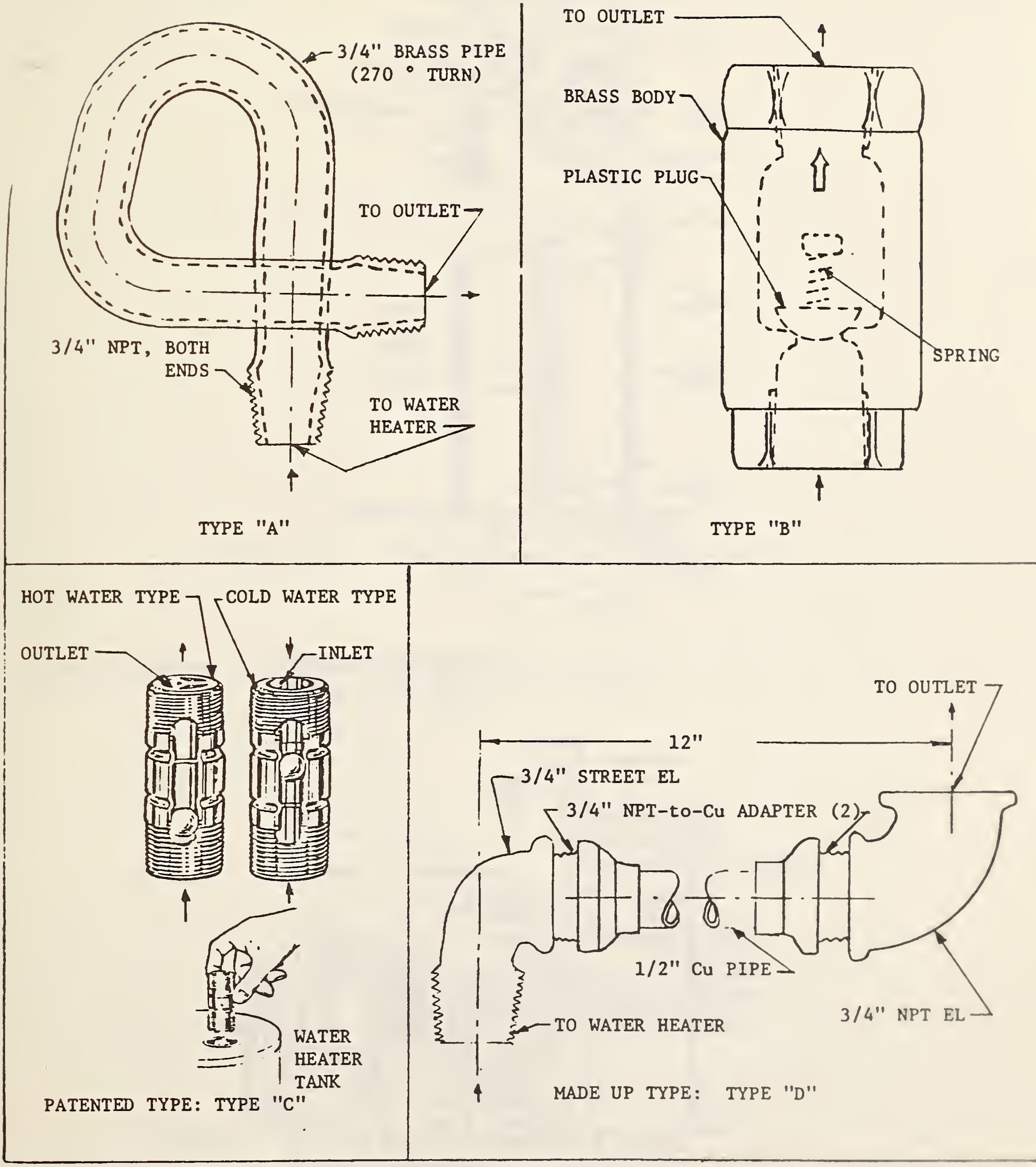
Fig.10. Diagram of the flow paths in a flue gas heat recovery system

(from Product Literature of Ther Heat Extractor Corp)



Flue gases ① coming from your furnace are extremely hot.
these gases pass through water sprays ②. The gases are cooled and the water is heated. The cooled gases ③ are expelled through a PVC vent pipe ④. Heated water in the ~~Efficiency~~ Booster's reservoir ⑤ is pumped by a high-efficiency electric pump ⑥ through the heat exchanger coil ⑦. Your furnace blower ⑧ draws cool household air through the heat exchanger coil, where it is pre-heated before entering the furnace.

Fig. 11. Example of one type of flue gas heat recovery system (Carrier)
(from Product Literature of the Carrier Corp)



NOTE: THE ABOVE DRAWINGS ARE NOT TO THE SAME SCALE

Fig. 12. Diagrams of heat traps
(Ref. 45)

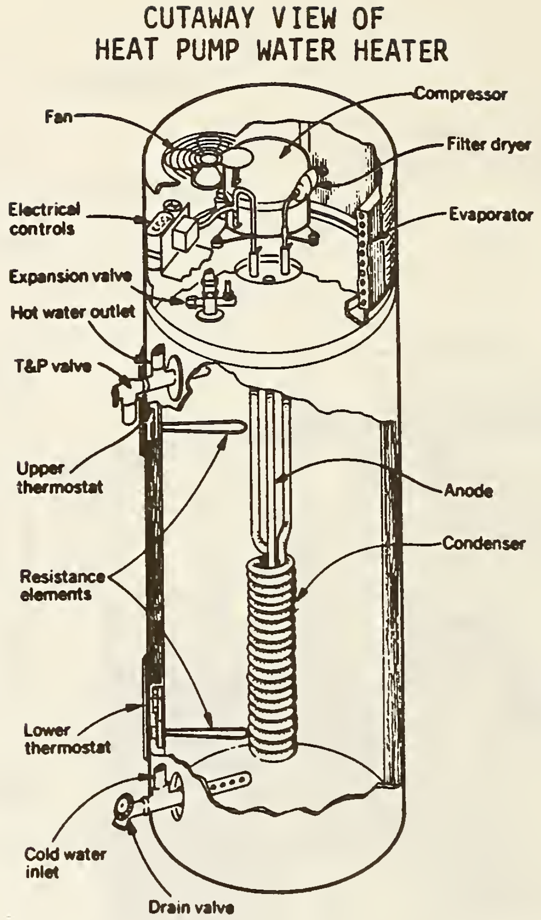


Fig.13. Diagram of heat pump water heater with integral condenser

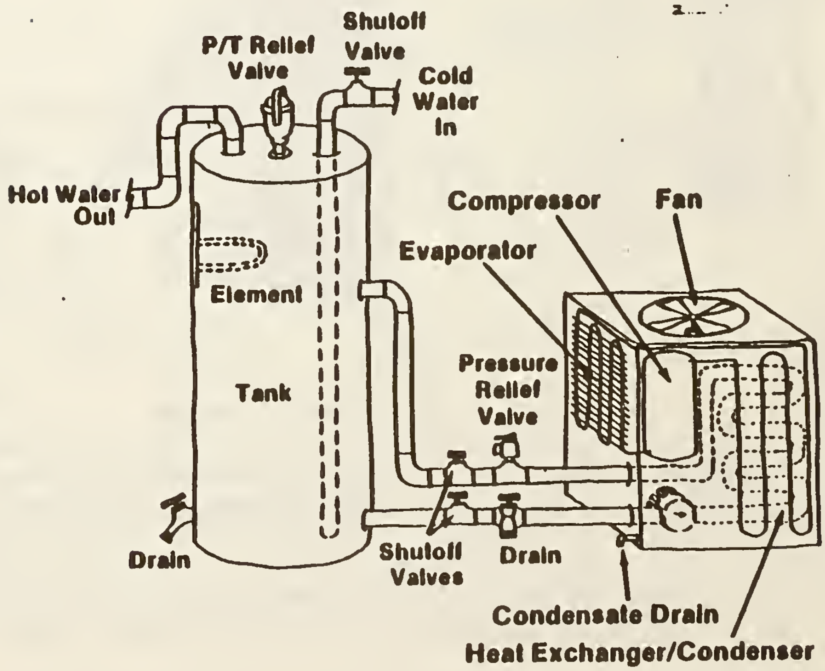
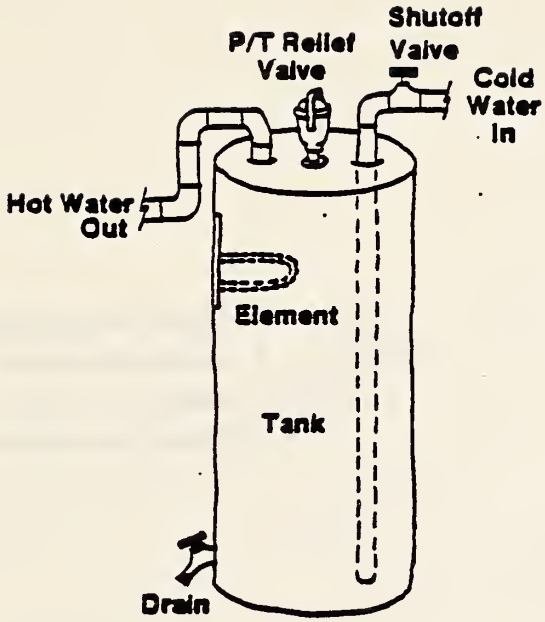


Fig.14. Diagram of a separated type of heat pump water heater
(from Ref. 53)



Electric water heater

Figure 15a   Electric resistance water heater

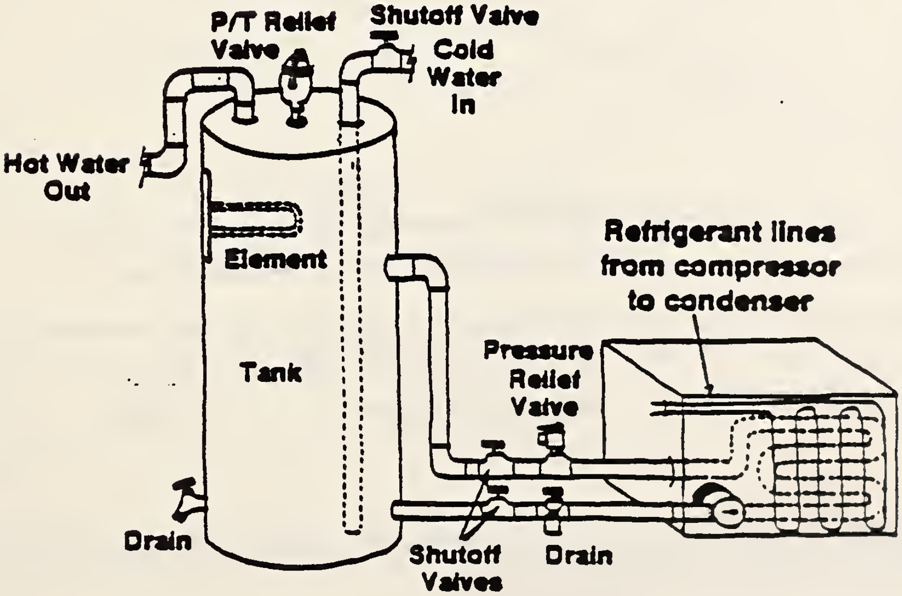


Fig.15.b. **Waste heat recovery unit**

Fig.15. Diagrams of an electric resistance water heater without and with a waste heat recovery unit

(from Ref. 53)

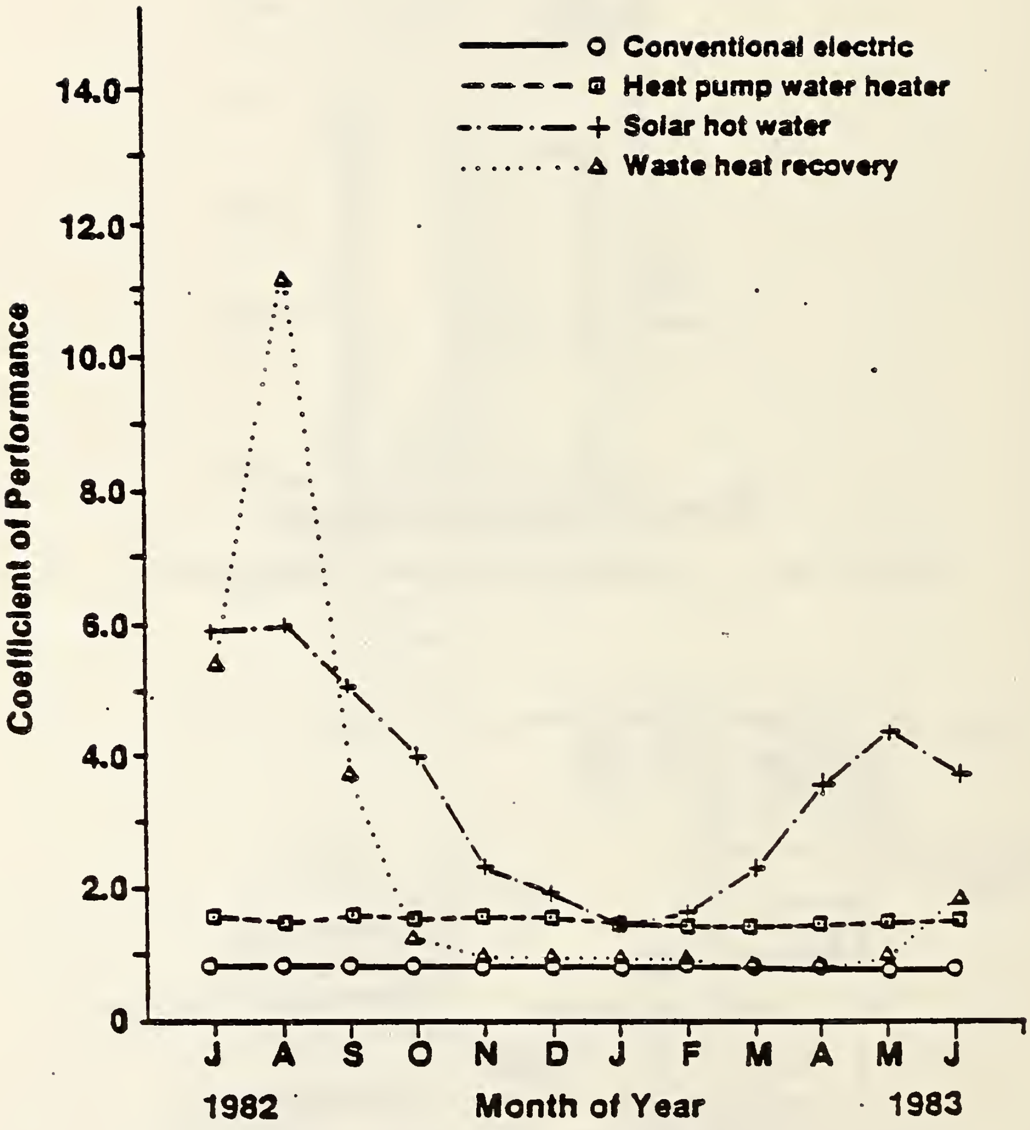


Fig.16. Monthly coefficient of performance of four different water heating systems in four Florida cities

(from Ref. 53)

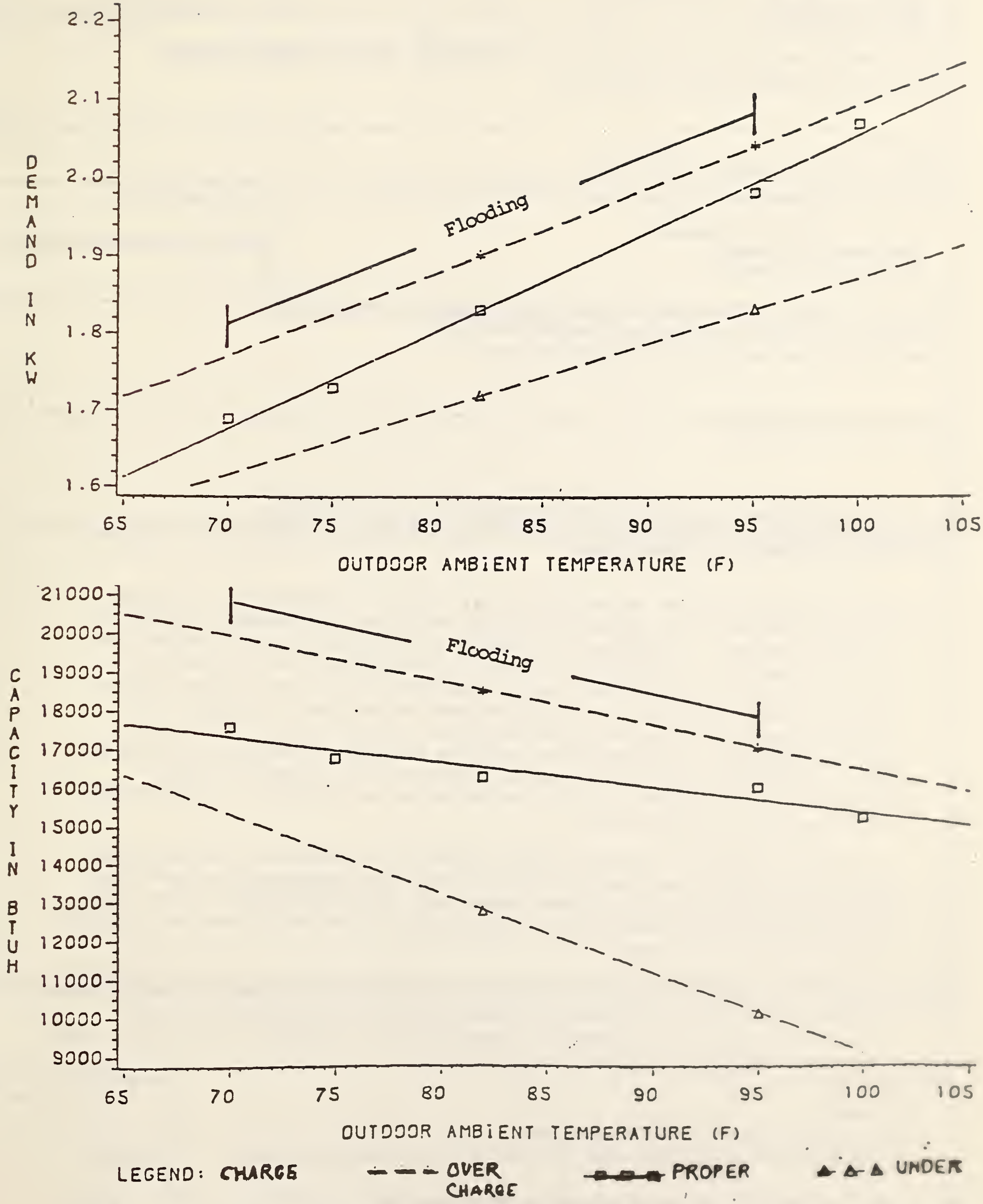


Figure 17. Effect of Refrigerant Overcharge or Undercharge on System Performance Compared With Proper Charge.
(from Ref. 58)

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 84-2870	2. Performing Organ. Report No.	3. Publication Date June 1984

4. TITLE AND SUBTITLE

PERFORMANCE AND SELECTION CRITERIA FOR MECHANICAL ENERGY SAVING RETROFIT OPTIONS FOR SINGLE-FAMILY RESIDENCES

5. AUTHOR(S)

Esher Kweller; Samuel Silberstein

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

DOE Office of Conservation and Renewable Energy
Weatherization Assistance Program Division

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Under the Weatherization Assistance Program the U. S. Department of Energy (DoE) provides funds for energy-conserving building improvements in homes of low-income persons. In proposing to modify the program to also provide funds for energy-conserving mechanical options, DoE requested that the National Bureau of Standards investigate energy-conserving mechanical options that may be suitable for inclusion in the Weatherization Assistance Program. This report estimates energy savings, and provides performance and selection criteria, standards, and installed costs for mechanical equipment options for single-family homes; all from prior studies reported in the literature. Performance and selection criteria are presented as advantages, disadvantages and limitations for each option.

Four broad categories of energy-saving mechanical options were investigated: space heating, water heating retrofit options, heat pump water heaters, and recovery of central air conditioner waste heat by desuperheaters. Gas- and oil-fueled forced-air furnaces and hydronic (hot water) space-heating equipment were treated in this report.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

derating; desuperheaters; energy conservation; heat pump water heaters; insulation; mechanical equipment; retrofits; space heating; vent dampers; waste heat recovery; water heating; weatherization

13. AVAILABILITY

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☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

74

15. Price

$10.00

USCOMM-DC 6043-P80